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THE STATIC MUSCLE LOAD IN DIFFERENT WORK POSITIONS: AN ELECTROMYOGRAPHIC STUDY*

By Sven Carlsöö

From the Department of Anatomy, Karolinska Institutet and the Department of Physiology, Kungliga Gymnastiska Central-institutet, Stockholm.

In order to ascertain which muscles and muscle groups are engaged in various standing work positions an electromyographic study was performed.

About twenty muscles or muscle groups were examined. Both coaxial needle electrodes and surface electrodes were employed.

The analysis of the muscle activity for different postures was based on action potentials recorded in a normal symmetric standing rest position. Among the different postures the rest position appears to require the least muscular effort for counterbalancing the effect of gravity on the various parts of the body. This state of equilibrium seems to be maintained by certain muscle groups, referred to here as the " prime postural muscles ". Only a part of the potential power of the postural muscles is utilized in maintaining the standing symmetric rest position. Some persons engage other muscles besides the prime postural muscles, possibly because they stand in such a way that the load distribution is not optimal, or they have weak prime postural muscles or because of poor muscular co-ordination as a consequence of " non-physiologic " postural habits.

When changing from the rest position to most of the other standing positions the load on the prime postural muscles is increased, and in many cases other muscle groups are activated as well. The sacrospinalis appears to be particularly susceptible to change in the load distribution. The muscles of the lower leg, which control the foot articulation, are also very susceptible to changes in body posture. However, a change in the position of the trunk need not result in an appreciable increase in the load on the muscles of the lower legs if the displacement of the centre of gravity of the trunk is compensated by a postural adjustment at the ankle, such that the point of intersection of the line of gravity of the body and the supporting area will be the same as in the symmetric standing rest position.

A change in posture of the hip- and knee-joints does not result in such a wide variation in activity of the muscles regulating the position of these joints as a postural change in the foot articulation and the vertebrae.

§ 1. Introduction

The standing body postures present a gravity problem. In the symmetric standing posture at rest the centre of gravity of the body lies roughly in the first sacral vertebra. This means that the vertical line through the centre of gravity falls a short distance in front of the transverse axes of motion of the vertebral column through, or close to, the transverse axis of motion of the hip, and a few centimetres in front of the transverse axes of the knee- and ankle-joints (Du Bois Reymond 1903, Hellebrandt *et al.* 1937, 1944, and Åkerblom 1948). For a mechanical analysis of the effect of gravity on the various joints, and to understand the importance of the action of the muscles in balancing the body, it would be more valuable to know the positions of the centres of gravity of the various body segments than to know the position of the centre of gravity of the whole body. It is obvious that the line of gravity of the body is not coincident with the lines of gravity for the various segments. In order to understand the mechanism that regulates the posture of the various

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joints it is necessary to know how each joint is affected by the weight of the parts of the body above it. The effect on the joint will depend on whether the line of gravity of that part of the body passes in front of, through or behind the axis of motion. The way in which the various joints are affected by the respective parts of the body can be ascertained indirectly by finding out which muscles are active in the different postures. A study of the position of the line of gravity of the whole body, however, provides an indication of where the lines of gravity of the various parts pass in relation to the transverse axes of motion of the ankle-, knee- and hip-joints and the vertebral column.

The line of gravity of the head in an adult passes in front of the neck-joints and the cervical spine. Moreover, the centre of gravity of the body as a whole must coincide fairly closely with that of the part of the body above the ankles, and this part will thus exert a forward-bending action on these joints. The position of the line of gravity of the part of the body above the hip-joints is not known in relation to the line of gravity of the body. The positional relationship between the transverse axis of motion of the knee-joints and the line of gravity of the part of the body above the knee-joints is also unknown, but is of little consequence in this connection. The knee angle—that is the angle behind the knee, defined approximately by the femur and the tibia—determines the effect of the force of gravity on the knee-joints. If this angle is less than 180° the weight of the body always tends to flex the knee, but if greater than 180° the weight of the body will tend to extend the knee-joint. More precisely the knee angle is defined as the angle formed in the central plane of the body, i.e. the sagittal plane, by the following two lines: the line connecting the transverse axis of motion of the hip-joint with the transverse axis of the knee-joint, and the line connecting the transverse axis of motion of the knee-joint with the axis of motion of the ankle-joint. In clinical estimations of this angle the various axes of motion have been represented by the top of the trochanter major, the lateral epicondyle and the lateral malleolus. In all the cases studied by the author the knee angle was less than 180°.

To balance the body and its various segments, muscles must be active in order to counteract the effect of the force of gravity on the different joints. To ascertain which muscles and muscle groups are active in various standing positions an electromyographic study was made. In these positions the muscles are acting for the most part isometrically. It is important to know, in a particular working posture, whether it is the more powerful, mechanically efficient muscles, or the weaker, less favourably located muscles that are active.

§ 2. Method

The electrical activity in the muscles was recorded either with a Disa myograph or an apparatus described elsewhere (Carlsöö 1956). In the studies of all the individual muscles, except the iliopsoas, coaxial needle electrodes were used. For recording from whole muscle groups where there was difficulty in distinguishing the individual muscles, surface electrodes were usually employed.

The following muscles and muscle groups were examined: sacrospinalis, neck musculature, gluteus maximus, gluteus medius, tensor fasciae latae, quadriceps femoris, sartorius, iliopsoas, biceps femoris, the medial ischio-

crural group, comprising the semimembranosus and semitendinosus, gastrocnemius, soleus, the adductors of the leg, flexor hallucis longus, peroneus longus and brevis, tibialis anterior, rectus abdominis, the external and internal oblique and the transverse abdominal muscles.

Except for the rectus, the anterior abdominal muscles were treated as a muscle group. According to the placement of the electrodes this muscle group was divided into an upper central part and a lower lateral part. The peroneus longus and brevis were treated as a unit and are referred to here as the peroneus muscle.

In the case of the superficial muscles a ' fleshy ' part of the muscle was located by palpation during voluntary contraction of the muscle, and the needle electrode was then inserted perpendicular to the skin. In the studies of flexor hallucis longus—not accessible for palpation—the needle electrode was inserted in a posterior-anterior direction at a point about 5 cm above the lateral malleolus and immediately lateral to the Achilles tendon. The position of the needle was checked by recording the potentials as the big toe was flexed voluntarily. (Fig. 13).

Each muscle or muscle group was examined on at least five subjects, and on each subject at least three muscles or muscle groups were tested. The subjects, 40 in number (37 male and 3 female), were students and personnel at the two institutions where the investigation was performed, with ages ranging from 19 to 42. There was no evidence that any of them had, or had had in the past, any postural abnormalities.

§ 3. Results

Position (1). The analysis of the muscle activity for different working postures was based on action potentials recorded in a normal, relaxed standing posture (Figs. 1a, b). In this position the feet were apart, with 20–30 cm between their medial borders, and the weight of the body was equally distributed on the legs with the arms hanging at the sides. The angle between the feet, assumed voluntarily by the subject, was in all cases small. This posture is referred to below as the *symmetric standing rest position, or the initial position.* Table 1, column 1, shows the results. The present investigation of the postural activity during easy standing mainly confirms previous findings (e.g. Åkerblom 1948; Floyd and Silver 1950, 1955; Joseph and Nightingale 1952, 1954, 1956; Basmajian and Bentzon 1954; Smith 1954; Joseph, Nightingale and Williams 1955; Joseph and Williams 1957; Portnoy and Morin 1958).

In distinction from some of these earlier works, in the present investigation activity has regularly been recorded in the biceps femoris and, in some cases, even in the medial ischio-crural muscles. Except for one case out of seven, in which activity was recorded in the gluteus medius, the gluteus muscles showed no action potentials. Except for two cases out of the seven tested, in which the tensor fasciae latae was active, no potentials were recorded in the flexors of the hip. The iliopsoas muscle is not accessible for insertion of ordinary needle electrodes, and surface electrodes were therefore used. They were placed in largely the same way as in Joseph and Williams' (1957) study. Neither in the investigations of Joseph and Williams nor in the present investigation could activity be recorded in the iliopsoas. The conditions relating

to the pick-up of the potentials by surface electrodes from a deep muscle are rather uncertain. In an experiment in which a long needle electrode was used, Floyd and Silver (1955) and Basmajian (1958) observed potentials in the iliopsoas in an upright position. Contrary to the findings of Floyd and Silver (1952) no activity was recorded from obliquus internus abdominis in the present investigation.

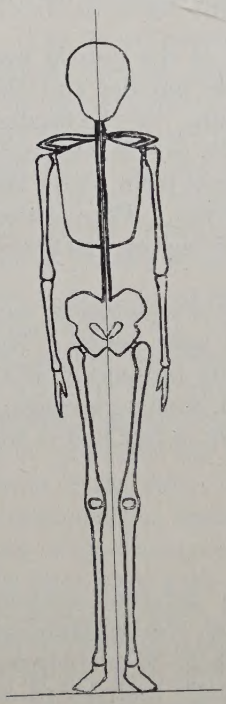

Figure 1a.

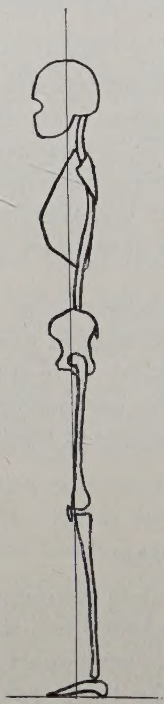

Figure 1b

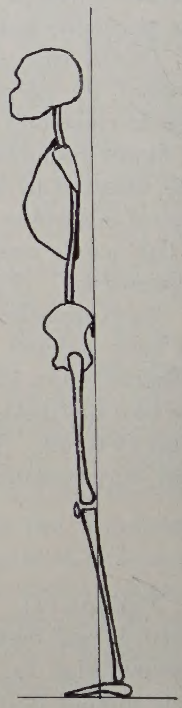

Figure 2.

In a symmetric standing position both the iliopsoas and the ischio-crural muscles are probably regularly in action. Therefore it is impossible from the distribution of the muscle activity to determine the position of the centre of gravity of the body segment above the hip-joint in relation to the transverse axis of the hip-joint.

In two subjects—S.W. and R.M.—out of the 12 tested, potentials were recorded from the peroneus. In the ankle-joint the peroneus acted synnergistically with the other plantar flexors, but, like the weight of the body, it also tended to have a pronating action on talo-calcaneo-naviculare-joint. However, as the tibialis anterior was also active in these two subjects—a muscle with a supinating action on the talo-calcaneo-naviculare joint—these muscles can counteract one another in this joint and hence stabilize it. In the other ten subjects, however, the peroneus and the tibialis anterior were silent in the symmetric rest position. This discrepancy is probably due to the different capacity of the muscle for relaxation or to the position of the ankle when the subject was standing in the symmetric rest position (see below).

The gastrocnemius and the ischio-crural muscles, except for the short head of the biceps femoris, are bi-articular muscles. Moreover, they act not only on the ankle or hip-joint but also on the knee-joint. Since the foot is firmly planted on the ground, these muscles are involved in a so-called closed muscle chain. This means that they act as extensors in the knee-joint. This is due to the fact that the moment arms on which these muscles act in the knee-joint are shorter than the arms on which they act in the ankle- and hip-joints (Hoepke 1957; Molbeck 1960).

Other symmetric positions

Starting from the symmetric rest position, the subjects were required to assume a series of postures. Prior to each series of recordings the subjects were instructed on the various postures and were asked to practise them. Each subject determined the details of the posture so that he could find his own relaxed and comfortable position. In order to ensure that the pick-up conditions did not change during the experiment and that the results were representative of the individual in question, each test was repeated once or twice.

Position (2). In the *forward leaning position,* Fig. 2, the body is inclined forwards from the ankles so that the weight is mainly on the balls of the feet. Owing to forward displacement of the centres of gravity of the various body segments it was found in all subjects that the action potentials recorded from the sacrospinalis, the neck musculature, the ischio-crural muscles, gastrocnemius, soleus, peroneus and the flexor hallucis longus were more marked in the forward leaning posture than in the symmetric standing position (Table 1, column 2, Figs. 13-16 and 18).

As a rule the tibialis anterior was silent in this position, but in the two subjects referred to above (S.W. and R.M.) the potentials were not completely abolished.

Position (3). In the *backward leaning posture,* Fig. 3, the body is inclined backwards from the ankles so that the weight of the body is mainly on the heels. The muscles, which in the initial position exerted an antagonistic and counteracting effect on gravity, showed in most cases in the backward leaning posture a much reduced activity, and at the same time some of the antagonists of these muscles were activated (Table 1, column 3, Figs. 13, 14, 16 and 17).

In the gastrocnemius and soleus the activity was in most cases noticeably less, but in two subjects no change in activity could be recorded (cf. Figs. 14 and 17). The tibialis anterior was engaged in all subjects. In the flexor hallucis longus the activity was usually abolished (Fig. 13), but in the peroneus it increased in all subjects (Fig. 16). The peroneus and flexor hallucis longus are mechanical synnergists in movements in the ankle, but they are mechanical antagonists in movements in the talo-calcaneo-naviculare-joint, which fact would seem to account for the different potentials recorded in the backward leaning posture. By virtue of their engagement in this backward stance, when the conditions of balance are, of course, less favourable than in the initial position, the peroneus and tibialis anterior can stabilize the talo-calcaneo-naviculare-joint.

Positions (4) and (5). *Slight* (Fig. 4) and *pronounced stooping postures* (Fig. 5). The trunk is bent forwards from the hips about 20° and 80° respectively. In the slight stooping posture the arms are held in front of the

body. The upper arms are held forwards 5-10° to the vertical, and the elbows bent so that the lower arms are horizontal, and the hands are on a level with the navel. In the pronounced stooping posture the upper arms are approximately vertical, with an elbow angle of 95-100°; the hands are then on a level with the knees. When recording from the neck musculature, however, the arms hung loosely at the sides in all the postures to avoid interfering activity from the trapezium muscle.

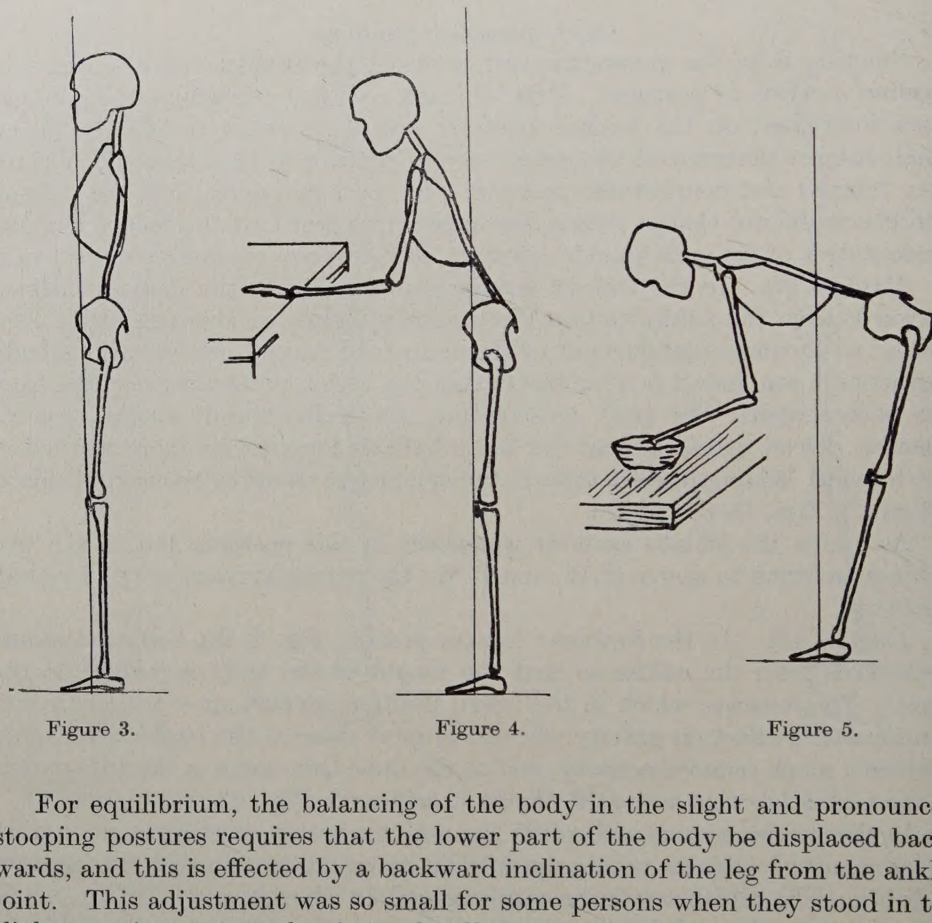

Figure 3. Figure 4. Figure 5.

For equilibrium, the balancing of the body in the slight and pronounced stooping postures requires that the lower part of the body be displaced backwards, and this is effected by a backward inclination of the leg from the ankle-joint. This adjustment was so small for some persons when they stood in the slight stooping posture that it was hardly noticeable, whereas for other persons it was quite obvious. These individual variations are reflected in the action potentials from the muscles.

In both these positions all the subjects showed high activity in the neck musculature, and the sacrospinalis and ischio-crural muscles. The more marked the stooping the greater the activity in these groups of muscles (Table 1, columns 4 and 5). A direct relationship of this nature between the degree of the stoop and the muscle activity was less common for the lower leg muscles. In some subjects the action potentials increased gradually in the gastrocnemius, soleus and flexor hallucis longus on moving from the initial position to the slight and marked stooping postures, but in others the activity in these muscles was greater in the former and less in the latter, more extreme

posture. In some the activity was eliminated in the more extreme posture, and less in the slight stooping posture than in the symmetric rest position.

It was evident from a supplementary study that this difference was closely connected with the position of the legs, and hence with the distribution of the load on the feet. In this supplementary study the subjects after training were required to assume a stooping posture and the potentials were recorded. The subject was then asked to change only the position of his legs by first reducing the backward inclination of the legs by a few degrees. When the legs are inclined backwards the load on the heels increases, while a more vertical position of the legs results in an increase in the load on the balls of the feet. The more the legs were pushed backwards and the load on the heels was increased, the less was the activity in the three muscles mentioned, and the more vertical the legs the more these muscles were loaded and the greater the activity (Fig. 19). In these postures there was a reciprocal innervation between these muscles on the one hand and tibialis anterior on the other.

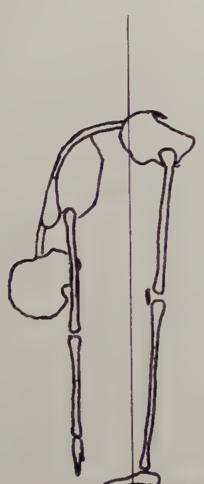

Figure 6a.

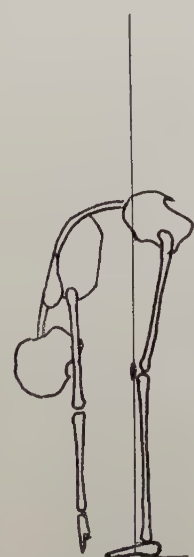

Figure 6b.

The load on, and hence the activity in, the peroneus seems also to be connected with the position of the leg and the foot. However, it is the distribution of the load in the medio-lateral as well as the ventrodorsal direction that determines the activity recorded from the peroneus. The more the load was moved to the lateral borders of the feet the greater was the activity of the peroneus. In all instances the peroneus was active in the stooping positions.

Position (6). *Fully bent posture* with the head, trunk and arms hanging in a relaxed state and the legs nearly straight (6a) or slightly bent (6b) (Figs. 6a and 6b). On changing from the pronounced stooping position to the fully bent posture the centre of gravity of the trunk was displaced slightly backwards and the compensatory backward inclination of the legs could decrease. In Table 1, column 6, it can be seen that the tibialis anterior was not engaged in the fully bent posture. This, together with the fact that the calf muscles

TABLE 1

Muscle	Position	(1a, 1b) Symmetric standing rest	(2) Forward leaning	(3) Backward leaning	(4) Slight stooping	(5) Pronounced stooping
	Sacrospinalis	+	++	(+), –	++	++
	Neck musculature	+	++	(+)	++	++
Anterior abdominal muscles	rectus abdominis	–	–	+	–	–
	superior medial part	–	–	(+)	–	–
	inferior lateral part	–	–	(+)	–	–
	Iliopsoas	–	–	–	–	–
	Tensor fasciae latae	–, +	–	+	–	–
Quadriceps femoris	rectus femoris	–	– –	+	–	–
	medial and lateral vastus	–	–	+	–	–
	Sartorius	–	–	–	–	–
	Adduktors of the leg	–	–	–	–	–
	Gluteus maximus	–	–	–	–	–
	Gluteus medius	–, +	–, +	–, +	–, +	–, +
	Biceps femoris	+	++	+	++	++
	Semitendinosus and semimembranosus	–, +	++	–	++	++
	Anterior tibialis	–, +	–, (+)	+, ++	–, +, ++	–, +, ++
	Gastrocnemius	–, +	++	–, (+)	–, +, ++	–, +, ++
	Soleus	+	++	–, +	–, +, ++	–, +, ++
	Flexor hallucis longus	–, +	++	–	–, +, ++	–, +, ++
	Peroneus	–, +	++	++	(+)+	(+)+

The Table shows in which positions the muscles are in action and in which they are not. A grading of the muscle activity of the respective muscles has been marked on the table according to the following code:

– indicates that no potentials at all were recorded in the muscle.
\+ indicates that definite action potentials were recorded.
++ indicates that the activity is much stronger than in the position marked with +.

TABLE 1

(8) Tiptoe	(9) Knee bending	(10) Asymmetric standing rest		(11) Rotated trunk		(12) Lateral bending	
		loaded side	unloaded side	ipsilateral side	contra-lateral side	loaded side	unloaded side
+,+(+)	+,+(+)	+	+	++	++	+	++
+	+	+	+	+	+	+	++
–,(+)	–	–	(+)	–	–	–	+
–	–	–	(+)	–	–,(+)	(+),+	+
–	–	–	(+),+	–,(+)	–	(+),+	+
–	–	–		–		–	–
(+),+	–,+	+,+(+)	–,+	–,+,++	–	–,+	–,+
–,+	++	–,+	–		–	–,+	–
–,+	++	–,+	–	–	–	–,+	–
–	–	–		–	–		–
–,(+)	–,(+)	–	–	–	–	–	–
–,+	–,+	–	–	–	–	–	–
–,(+),+	–,+	+,+(+)	–,+	–,+,++	,+	–,+	–,+
+,+(+)	+,+(+)	+	+	+	+	+	+
(+),+	+	–,+	–,+	–,+	–,+	–,+	–,+
–,+,++	–,+,++	–,+	–,+	–,+	–,+	–,+	–,+
++	+,++	,+	,+	,+	–,+	–,+	–,+
++	++	+	+	+	+	+	+
++	–,+,++	–,+	–,+	–,+	–,+	–,+	–,+
++	–,+,++	+,+(+)	–,+	–,+	–,+	–,+,+(+)	–,+

+(+) indicates that the degree of activity is between + and ++.

(+) indicates that the activity has decreased somewhat compared with the degree of activity marked with + but not completely ceased.

If two or three gradings are present within the same square it shows that individual variations exist. Thus +,– indicates that some subjects engage the muscle, some not.

often were highly active in this posture, suggests that the legs were in a fairly vertical position and that there was a displacement of the load on to the balls of the feet (Fig. 20).

As other workers have demonstrated (Floyd and Silver 1955; Portnoy and Morin 1958), the sacrospinalis is completely relaxed in full trunk flexion (Fig. 21). The counteraction of gravity is probably taken over by the ligaments of the spinal column. The compressed abdominal and pelvic organs might also offer passive resistance, which considerably reduces the load on the dorsal muscles. The neck musculature, on the other hand, is still in action and to about the same extent as in the stooping postures. As regards the other muscles that were engaged in the pronounced stooping posture, the potentials usually increased on changing to the fully bent posture.

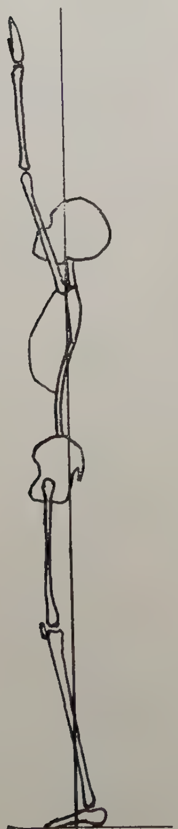

Figure 7.

Figure 8.

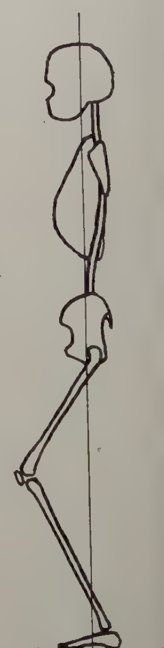

Figure 9.

Some of the subjects felt uncomfortable when standing in the fully bent posture with the same knee position as in the initial position, and thought that it would be more comfortable if instead they could stand with the knees slightly bent. A supplementary study showed that when such a position was assumed with the knees bent about 20°, the quadriceps and adductors were engaged—in two cases, also the gluteus maximus—and the potentials from the soleus, peroneus and flexor hallucis longus increased slightly, whereas those

from the gastrocnemius were smaller, or in some instances abolished, and in the ischio-crural muscles much reduced. This bending of the knees was stated to be more comfortable and less tiring. It resulted in fairly marked changes in the load on the muscles. The relief that the subjects felt was probably due mainly to a better distribution of the activity between several muscles (Figs. 20 and 22). Thus, the powerful quadriceps were now engaged for stabilization of the knee-joints, and some of the load could be removed from the ischio-crural muscles and gastrocnemius. The marked stretching of the passively insufficient ischio-crural muscles may also have contributed to the discomfort felt in that position.

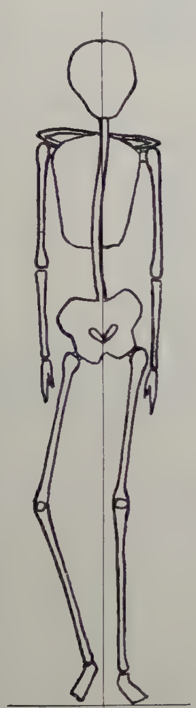

Figure 10.

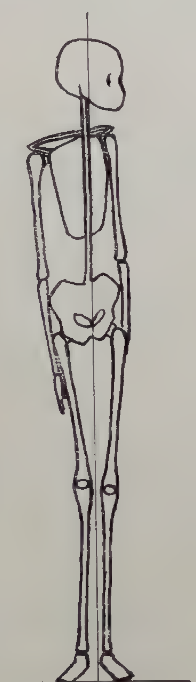

Figure 11.

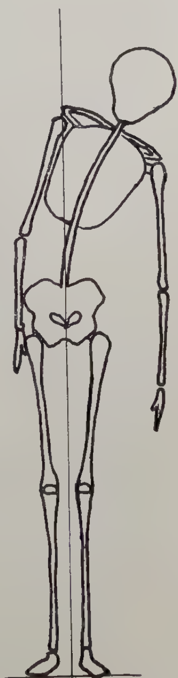

Figure 12.

Position (7). *Backward bending posture.* The gaze is fixed on a spot on the ceiling just above the head, and the spot is pointed to by raising one arm (Fig. 7). In all subjects the activity recorded from the sacrospinalis and the ischio-crural muscles was much reduced in the backward bending posture (Table 1, column 7). In this respect the activity resembles that recorded in the backward leaning posture. The difference between the distribution of the activity in some other muscles during standing in the backward bending and backward leaning postures probably depends upon the compensatory movements in the ankle-joint and knee-joint in the backward bending posture.

Position (8). *Tiptoe position.* From the initial position the heels are raised above the floor 1-2 cm (Fig. 8). In this position the plantar flexors are strongly engaged (Table 1, column 8). The reduced supporting area, the associated difficulty in balancing the body and the need for stabilizing muscle

forces probably account for the wide variation in the increase in activity recorded. Generally, the tiptoe position is an extremely tiring one for the muscles.

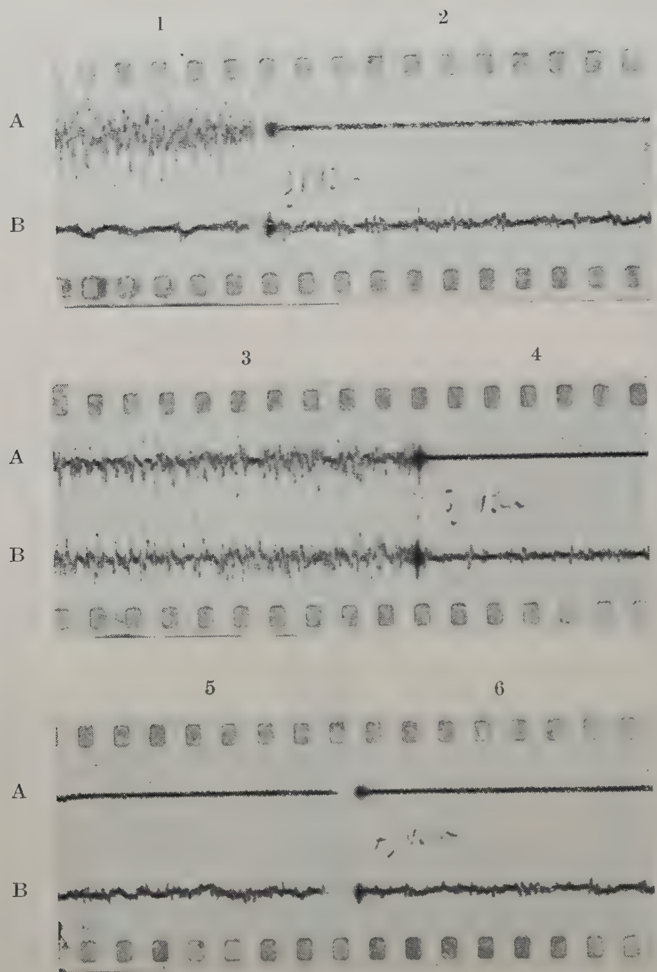

Figure 13. A : m. flexor hallucis longus, B : m. gastrocnemius. Mom. 1 : voluntary flexion of the great toe, mom. 2, 4 and 6 : symmetric standing rest position, mom. 3 : forward leaning position, mom. 5 : backward leaning position.

Position (9). *The knee-bending posture.* With the upper trunk and feet in the initial position, the knees are bent so that the angle between the thighs and the lower legs is about 135° (Fig. 9). This posture was without doubt the one that the subjects found most difficult to maintain. During the tests the knee angle had to be continuously changed, and the position of the trunk and the spine varied. Moreover, the assumption of identical postures on different occasions of examination presented difficulty, and consequently the estimate of the muscle load in this position was unreliable. No definite results could therefore be obtained for certain muscles, as Table 1, column 9, shows. For all subjects and in all tests a marked activity was recorded for the quadriceps and soleus.

Asymmetric standing postures

In these asymmetric postures the arms always hung loosely at the sides.

Position (10). *Asymmetric standing rest position.* This posture differs from the symmetric standing posture in that the weight of the body is borne mainly by one leg (Fig. 10). In this posture there was, as expected, an increase in the activity in the muscles of the supporting leg and a reduction in the activity of

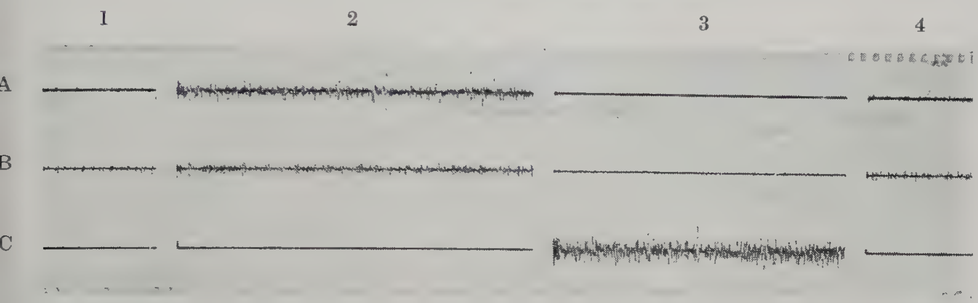

Figure 14. A : m. gastrocnemius, B : m. soleus, C : m. tibialis anterior. Mom. 1 and 4 : symmetric standing rest position, mom. 2 : forward leaning position and mom. 3 : backward leaning position.

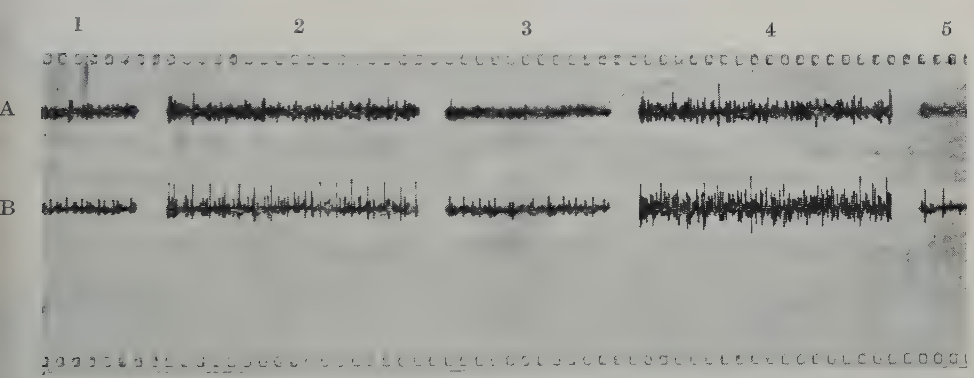

Figure 15. A : m. sacrospinalis sin., B : m. sacrospinalis dext. Mom. 1, 3 and 5 : symmetric standing rest position, mom. 2 : forward leaning position, mom. 4 : symmetric standing rest position with the arms moved forwards.

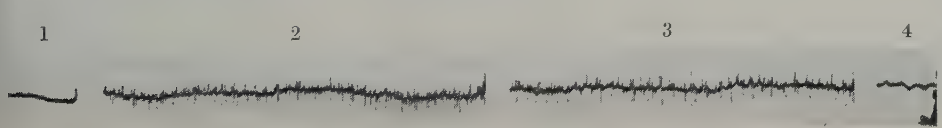

Figure 16. M. peroneus. Mom. 1 and 4 : symmetric standing rest position, mom. 2 : forward leaning position, mom. 3 : backward leaning position.

those of the ‘ unloaded ’ leg (Table 1, column 10). The most notable change was an increase in the activity in the peroneus. This was probably due to the fact that the load on the supporting foot was acting more laterally than in the symmetric position. A marked increase in the load on the gluteus medius and tensor fasciae latae of the supporting leg was recorded regularly, as well as on the abdominal muscles of the unloaded side. This was probably due to the

lateral tilting of the pelvis. Two of the subjects preferred to stand with the supporting leg extended as far as possible; they considered that they could stand more firmly in this way. In these subjects a high activity was also recorded in the quadriceps.

Position (11). *Rotated trunk posture.* The upper trunk is turned 20° about the vertical axis of the body (Fig. 11). An erect standing position with upper trunk turned involves a rotatory movement of the spine and the pelvis. An increase in activity was recorded in the tensor fasciae latae and gluteus medius of the ipsilateral leg (the ipsilateral side is the one towards which the movement is made) (Table 1, column 11). It should be noted again that some of the rotators of the hip-joint were not examined in this study. It is quite possible that the rotation of the pelvis occurring in this posture is largely affected or governed by these deep outward rotators.

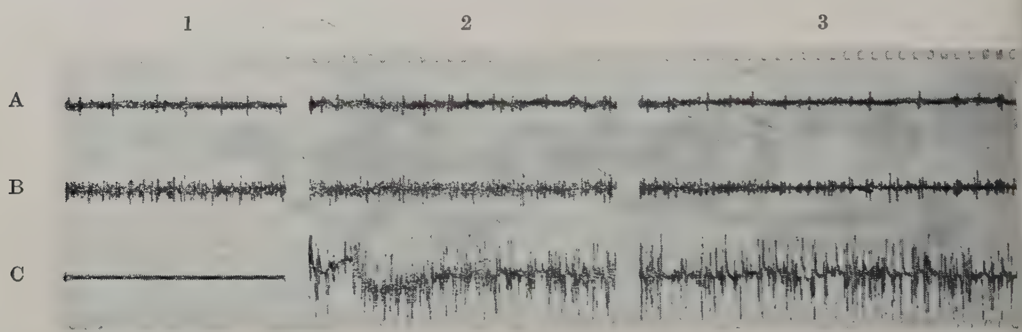

Figure 17. A : m. gastrocnemius, B : m. soleus, C : m. tibialis anterior. Mom. 1 : symmetric standing rest position, mom. 2 : backward leaning position, mom. 3 : backward bending position.

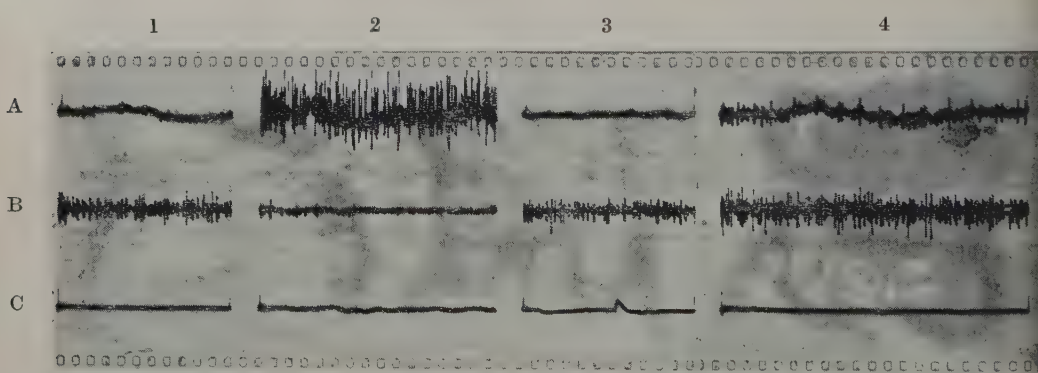

Figure 18. A : m. gastrocnemius, B : m. soleus, C : m. tibialis anterior. Mom. 1 and 3 : symmetric standing rest position, mom. 2 : tiptoe position, mom. 4 : forward leaning position.

The sacrospinalis is powerfully engaged in this position, for a large rise in activity was recorded bilaterally. Activity of the oblique abdominal muscles would perhaps have been expected on anatomic grounds, but in only two instances was any appreciable involvement recorded. If, however, the pelvis was fixed by having the subject sit on a stool and perform the turning movement to the same extent as in the standing position, potentials were regularly

recorded. It thus appears as if it is the deep back muscles that are primarily involved in small turning movements—these are also in action even in the initial position—the abdominal muscles being mobilized secondarily.

Position (12). *Lateral bending posture.* The upper trunk is bent about 20° to one side (Fig. 12). In all instances there was a pronounced increase in activity in the sacrospinalis, neck musculature and the abdominal muscles on the contralateral side (Table 1, column 12). If no compensatory movement in the talo-calcaneo-navicular-joint was performed—and in some subjects it could not be observed—the load on the ipsilateral leg was similar to that on the supporting leg in the asymmetric rest position, and the changes in activity

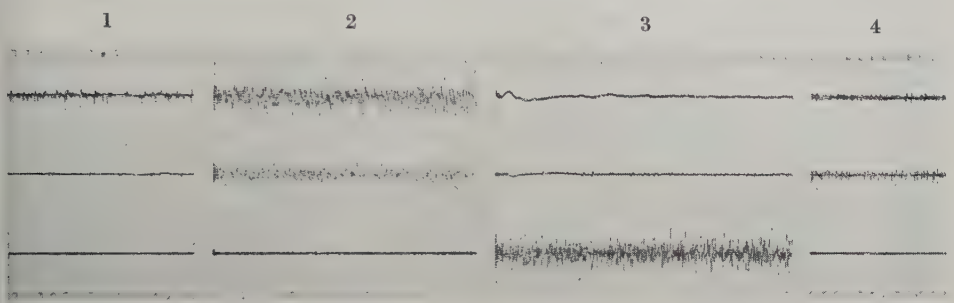

Figure 19. A : m. gastrocnemius, B : m. soleus, C : m. tibialis anterior. Mom. 1 : pronounced stooping posture (self-chosen position), mom. 2 : pronounced stooping posture (the subject is asked to put the load mainly on the balls of the feet), mom. 3 : pronounced stooping posture (the subject is asked to put the load mainly on the heels), mom. 4 : symmetric standing rest position.

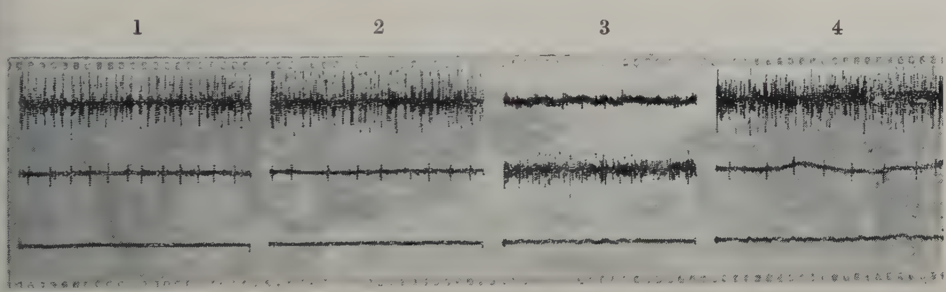

Figure 20. A : m. gastrocnemius, B : m. soleus, C : m. tibialis anterior. Mom. 1 : pronounced forward bending position, mom. 2 and 4 : fully bent position, mom. 3 : fully bent position with about 20° voluntary knee bending.

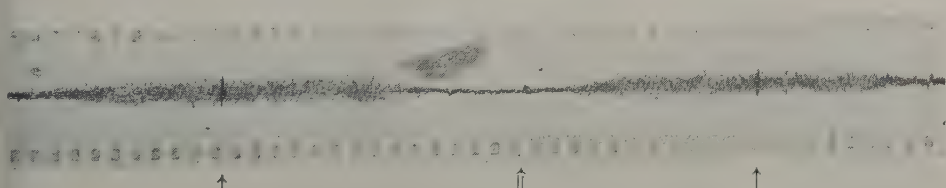

Figure 21. The activity in m. sacrospinalis during slowly forward-downward bending immediately followed by a return to the symmetric standing rest position. The arrows (↑) indicate when the trunk is bent approximately 45° forward and the arrow (⇑) indicates that the direction of the movement changes.

within the abdominal muscles were thus practically the same. Two subjects appeared to prefer to stand with the knee of the ipsilateral leg extended. This is indicated by the recorded activity in the quadriceps on this side.

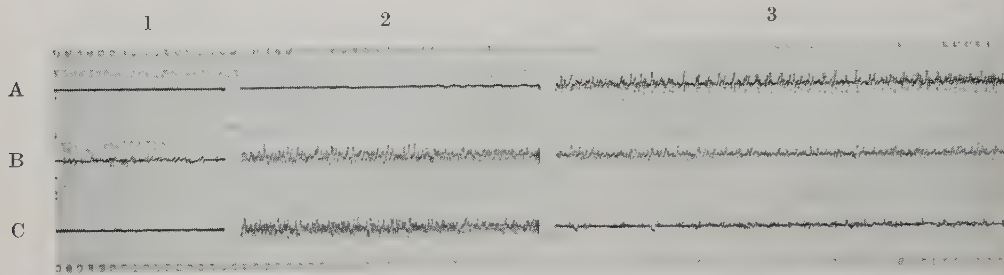

Figure 22. A : m. quadriceps, B : m. biceps femoris, C : m. semitendinosus. Mom. 1 : symmetric standing rest position, mom. 2 : fully bent position, mom. 3 : fully bent position with about 20° voluntary knee bending.

§ 4. Discussion

Of all the postures examined, the standing symmetric rest position appears to require the least muscular effort for counterbalancing the effect of gravity on the various parts of the body. This state of equilibrium seems to be maintained by certain muscle groups, referred to here as the ' prime postural muscles '. Among these are the neck musculature, the sacrospinalis, the ischio-crural muscles (especially the biceps femoris) and the calf muscles (primarily the soleus). The electrical activity recorded in the muscles in the symmetric standing position was considerably lower than that in certain other standing positions. In other words, only a part of the potential power of the postural muscles is utilized in maintaining the standing symmetric rest position. The prime postural muscles are among the more powerful muscles of the body. Some persons engage other muscles besides the prime postural muscles when standing in the symmetric rest position, possibly because they stand in such a way that the load distribution is not optimal, or because they have weak prime postural muscles, but more probably because of poor muscular co-ordination as a consequence of ' non-physiologic ' postural habits.

When changing from the initial position to most of the other standing positions the load on the prime postural muscles is increased, and in many instances other muscle groups are activated as well. The sacrospinalis appears to be particularly susceptible to changes in the load distribution, very small changes in the position of the trunk sufficing to produce appreciable variations in the electrical activity recorded from this muscle. With the exception of the fully bent, backward bending and backward leaning postures, all the positions involved an increase in the load on the sacrospinalis. One should therefore ensure that in standing working positions the trunk and spine deviate as little as possible from their position in the symmetric standing rest position. The muscles of the lower leg, which control the foot articulation, are also very susceptible to changes in body posture. Several of these muscles, including the tibialis anterior, flexor hallucis longus and peroneus, are relatively weak

and mechanically inefficient. As a rule these muscles are engaged to a small extent, if at all, in the symmetric rest position. The tibialis anterior lies in an osteo-fibrosis space, which offers a strong resistance to the contraction of the muscle, and as a result fatigue and pain may be produced in the anterior part of the lower leg. Any working posture requiring the continuous engagement of the tibialis anterior should therefore be avoided.

The distribution of the weight of the body on the foot would seem to be the prime factor in determining the load borne by the muscles of the lower leg. The minimum loading of these muscles occurs in the symmetric standing position. A change in the position of the trunk in one direction or another—for instance, in bending forwards—need result in no appreciable increase in the load on the muscles of the lower legs. The increase will be the minimum if the displacement of the centre of gravity of the trunk is compensated by a postural adjustment at the ankle, such that the point of intersection of the line of gravity of the body and the supporting area will be the same as in the symmetric standing rest position.

In the case of the stooping posture there were only a few subjects who spontaneously assumed such a well-balanced position. Many of them placed too large a part of the load on the anterior part of the foot, and then powerfully engaged the soleus, gastrocnemius and such relatively weak muscles as the flexor hallucis longus and peroneus. Others placed too much of the load on the heels, so that the tibialis anterior and the peroneus muscles, which do not well tolerate continuous loading, were strongly activated.

In the asymmetric standing position, the load, and consequently the electrical activity, increased in the muscles of the supporting leg. At the same time the activity in the muscles of the unloaded leg, especially those of the lower part, decreased and was often even abolished. By assuming asymmetric working postures, and using the right and left leg alternately as the main support, the leg muscles are therefore periodically unloaded and relaxed. However, a unilateral asymmetric position is more fatiguing than a symmetric standing posture. The muscles regulating the position of the hip-joint and knee-joint are usually powerful groups. This would explain why a change in posture of the hip- and knee-joints does not result in such a wide variation in activity as a postural change in the foot articulation and the vertebrae. A slight increase or decrease in the load is of less importance for a powerful than for a weaker muscle.

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En vue d'examiner de quelle façon les muscles ou les groupes musculaires entrent en fonction dans différentes attitudes de travail, nous avons pratiqué une étude électromyographique.

Près de 20 muscles ou groupes musculaires ont été examinés. Nous avons employé des aiguilles à électrodes coaxiales et électrodes de surface.

L'analyse de l'activité musculaire pour les diverses attitudes était basée sur l'étude des potentiels d'action recueillis lors d'une position de repos normale et symétrique, le sujet étant debout. Parmi les différentes positions, celle de repos semble demander le moindre effort musculaire pour contrebalancer l'effet de la pesanteur. Cet état d'équilibre semble être maintenu par certains groupes musculaires pouvant être dénommés " muscles posturaux principaux ". Une partie seulement de la force potentielle des muscles posturaux est utilisée pour maintenir cette position de repos. Quelques personnes utilisent d'autres muscles en plus de ces muscles

posturaux principaux, sans doute du fait qu'elles adoptent une attitude telle que la répartition pondérale n'est pas optimum, ou bien parce qu'elles possèdent des groupes musculaires déficients, ou bien encore du fait d'une mauvaise coordination, elle-même conséquence d'habitudes posturales " non physiologiques ".

Lorsque le sujet change de position, l'activité des muscles posturaux principaux est accrue et, très souvent, d'autres groupes musculaires interviennent. Les muscles de la masse commune semblent être particulièrement influencées par des changements de répartition pondérale. Les muscles des membres inférieurs qui contrôlent les articulations sont également très sensibles aux changements de position. Pourtant un changement de position du tronc ne provoque pas nécessairement un accroissement très important de l'activité musculaire des membres inférieurs, si le déplacement du centre de gravité du tronc est compensé par un ajustement postural de la cheville de telle façon que la projection du centre de gravité sur le polygone de sustentation se fasse au même point que dans la position de repos.

Un changement de position des articulations sacro-iliaques ou des genoux n'entraîne pas une aussi grande variation d'activité des muscles intéressés qu'un changement d'attitude des articulations du pied et de la colonne vertébrale n'en provoque sur ces mêmes muscles.

Um festzustellen, welche Muskeln und Muskelgruppen bei verschiedenen Arbeits-Stellungen im Stehen beansprucht werden, wurde eine electro-myographische Untersuchung durchgeführt. Zur Messung wurden sowohl coaxiale Nadelelektroden als auch Oberflächenelektroden gebraucht.

Die Analyse der Muskel-Aktivität bei verschiedenen Stellungen beruhte auf den beim Stehen in normaler symmetrischer Ruhe-Stellung registrierten Aktionspotentialen. Unter den verschiedenen Stellungen scheint die Ruhe-Stellung die kleinste Muskelanstrengung zu erfordern, und den Schwerkraftseffekt auf die verschiedenen Teile des Körpers auszubalancieren. Dieser Gleichgewichtszustand scheint durch bestimmte Muskelgruppen gehalten zu werden, die hier als " Haupt-Haltungsmusklen " bezeichnet werden. Nur ein Teil der potentiellen Kraft der Haltungsmuskeln wird gebraucht, um die symmetrische Ruhe-Steh-Stellung aufrecht zu erhalten. Einige Personen benutzen noch andere Muskeln neben den Haupt-Haltungsmuskeln, vielleicht weil sie so stehen, dass die Lastverteilung nicht optimal ist, oder weil sie schwache Haupt-Haltungsmuskeln haben, oder wegen einer schlechten Muskel-Coordination als Folge von " nicht physiologischen " Haltungsgewohnheiten.

Wenn man von der Ruhe-Stellung zu den meisten anderen Steh-Stellungen überwechselt würde die Belastung der Haupt-Haltungsmuskeln vergrössert, und in vielen Fällen werden dabei auch andere Muskelgruppen aktiviert. Die Wirbelsäule scheint besonders leicht auf Aenderungen der Lastverteilung zu reagieren. Die Muskeln des unteren Beines, die das Fussgelenk kontrollieren, reagieren gleichfalls sehr fein auf Veränderungen der Körperhaltung. Eine Veränderung der Haltung des Rumpfes braucht jedoch nicht eine nennenswerte Lastzunahme in den unteren Beinmuskeln zu ergeben, wenn die Verschiebung des Schwerpunktes des Rumpfes durch eine Haltungs-Berichtigung im Fussgelenk kompensiert wird, sodass der Schnittpunkt der Schwerpunktslinie des Körpers mit der Unterstützungsfläche der gleiche bleibt wie bei der symmetrischen Ruhe-Stellung. Eine Aenderung der Haltung der Hüft- und Knie-Gelenke ergibt nicht eine so starke Veränderung der Aktivität der Muskeln, die die Haltung dieser Gelenke regulieren wie ein Stellungswechsel im Fussgelenk und in der Stellung der Wirbel.

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MONOPHOTOGRAMMETRIC DETERMINATION OF BODY VOLUME

By William R. Pierson

Los Angeles County Osteopathic Hospital, Los Angeles, California

A method of determining body volume by means of monophotogrammetry is described. Comparisons of volume determined by this method with that by water displacement resulted in a difference of 1·79 per cent. This represents 'substantial agreement' and, in addition, the monophotogrammetric method eliminates the major disadvantages of the water displacement, hydrostatic weighing, and formulae methods.

§ 1. Introduction

The measurement of body volume has long been of interest to human biologists, for it is primarily from estimates of human body volume that formulae for the estimation of specific gravity, 'body fat', and fat-free body mass have been derived. The basic technique for determining body volume involves water displacement or hydrostatic weighing. Kolrausch (1930) described a modification of the former which eliminates some of the more obvious sources of error, but von Döbeln (1956) presents evidence that neither water displacement nor Kolrausch's modification are adequate for accurate determinations. Other than technical difficulties, certain problems are associated with both water displacement and hydrostatic weighing: the equipment is expensive, considerable space is required, the water must be maintained at a constant temperature and must stand for a period of hours to prevent small bubbles from forming on the skin of the subject, respiration is a difficult variable to control, and some classes of subjects object to spending the time underwater requisite to accurate readings. So few studies have repeated measurements that the reliability of the various techniques is practically unknown. Matuschek (1960) and von Döbeln (1956) have described some of these techniques and Boyd (1933) presented a comprehensive survey of the literature for the years 1757 to 1933. The literature to 1958 has been summarized by Cowgill (1958).

In an attempt to circumvent the above-mentioned difficulties, some investigators have considered the possibilities of photogrammetry. Weinbach (1938) presented a method of estimating body volume which had as its underlying assumption that serial horizontal sections through the body are elliptical and the areas and perimeters of these ellipses can be calculated from the measurement of their axes on photographs. He made no comparisons with objects of known volume nor with the results of water displacement. The technique described by Geoghegan (1953) assumed that the human body may be divided into levels (isopleths) whose surface areas approximate sections of right cones. Twelve photographs per subject are required and similarity of the poses to those of the Hindu god Shiva led to the naming of the technique 'Shivan'. He compared the results of the 'Shivan' technique with those obtained through various formulae. Statistical analyses by the present writer reveal correlations from $r=0·86$ to $r=0·99$ for these comparisons. However, there is no way of knowing how accurately the formulae measure body volume.

The rapid post-war advances in photomapping techniques have suggested nontopographic stereophotogrammetry as a valid means of determining human body volume (Pierson 1957). Hertzberg *et al.* (1957) presented a contour ' map ' of a male subject with a contour interval of one-half inch, and then plotted profiles from this ' map '. Although the purpose of their study was to extract body dimensions, they state, ". . . from subsequent work we have found that the measurements of total body volume and the volumes of individual body segments very closely approximate those calculated by the Dubois formula (Dubois and Dubois 1916)." An evaluation of this statement is difficult because no data are given and the cited formula (Du Bois and Du Bois 1916) is not a means of determining body volume but a method for estimating total body surface area from height and weight. However, were there a high correlation with a formula method, as in Geoghegan's study, the expense of photogrammetry could be avoided by the use of the simpler method. It might then be said that stereophotogrammetry validates the use of formulae. Using Wild's method (Wild 1954) of calculating total volume, Pierson (1959) compared the volume of a basketball as determined from stereophotogrammetry with that as determined by water displacement. He found the difference to be 1·2 per cent and concluded that stereophotogrammetry is a valid technique for estimating body volume and that errors of less than three per cent may be expected.

There are reasons why stereophotogrammetry might not be employed very often as a research or diagnostic tool : the mathematics and photography are expensive and complicated, and the plotting of the contours requires highly skilled personnel and very costly apparatus. The outcome of the stereophotogrammetric process is a contour ' map ' of the human body from which volume may be calculated. It is the purpose of this study to present a simple and inexpensive method of monophotogrammetry which will result in a reasonably accurate ' map ' and to determine the accuracy of volumes calculated from that ' map '.

§ 2. Method

Alternating red, yellow, green, and clear transparent acetate strips (Chart-Pak), one-eighth inch wide, were placed in juxtaposition on two sheets of clear acetate film. These two sheets were then mounted approximately 9 in. apart on a turntable in such manner that the colours were in line with each other. A male model was placed between the prepared sheets and photographs were taken from the front and back. The dimensions of this figurine were approximately one-third those of a 5 ft 6 in. adult male. Because this was an anatomical figure, many of the muscle groups were over-emphasized and are not truly representative. In some places this slightly obscured the contour lines, a situation which would not occur in the normal human subject.

The light source for the photography was four two-cell flashlights, two placed 12 ft on either side of the model, which projected the coloured strips onto it (see Fig. 1). Photography was accomplished by means of a Contax III camera with a 5 cm objective and Anscochrome film. The exposures were of 10 sec duration at $f=8$. The 35 mm colour transparencies resulting from the photography were projected onto drafting cloth and tracings were made. These are presented as Fig. 2. The numbered lines on this figure represent the

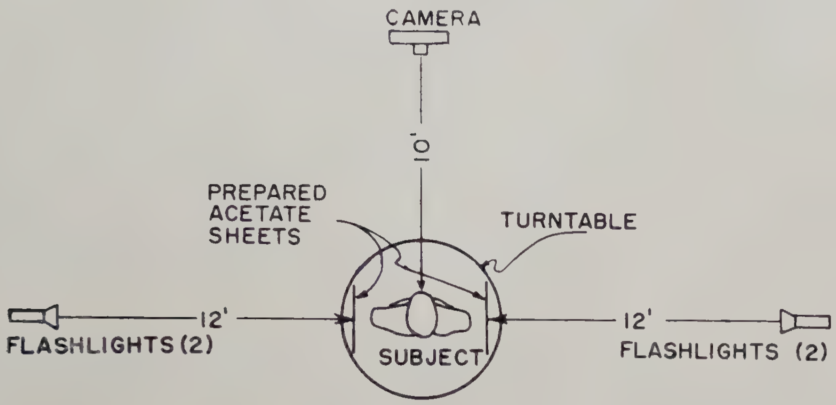

Figure 1. Schematic layout for the experimental photography.

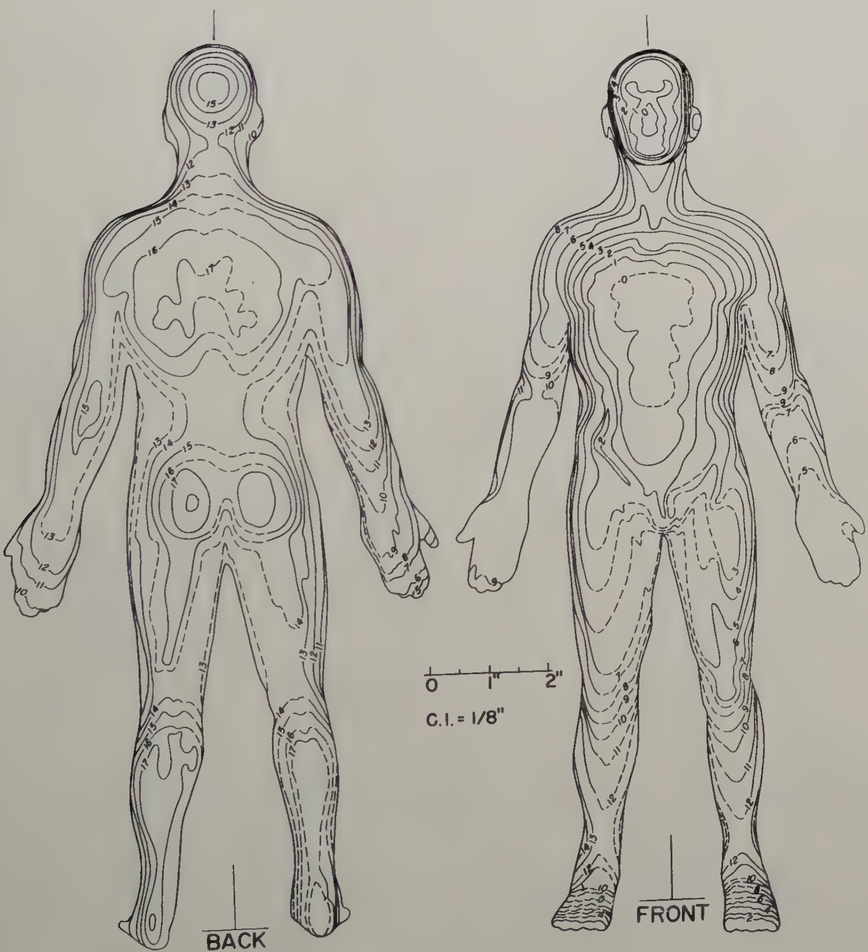

Figure 2. Contoured "map" of model of adult male. Broken lines show areas partially obscured.

lines of demarcation between adjacent coloured strips as they were projected on the model. Each of these lines may be considered as identifying an isopleth of certain shape and area, and with a height of one-eighth inch. They are comparable to what are termed ‘ contour lines ’ on topographic maps. The horizontal scale of Fig. 2 was 1 : 1·23, that is 0·23 times larger than the model itself. This was not through design, but expediency, because it is not necessary to draw the ‘ map ’ to any particular scale so long as it may be determined from the finished product. The easiest way to do this is to compare distances between known points on the original with those between the same points on the ‘ map ’. Twenty such comparisons were made for the present study and the mean of these was considered as the scale.

The area of each isopleth was determined by computing the mean of five readings from a LASICO model 1100 c.p. rolling planimeter, and the formula of Wild (1954) was used to calculate the volume of the model. In this formula, $V = (a + 2b, 2c \ . \ . \ . \ + 2n)/2$ (contour interval), a was the O contour line and the contour interval was $\frac{1}{8}$ in. (0·31750125 cm).

The total volume as estimated from 20 measurements by the water displacement method was 932·25 cm^3, with a sample deviation of 36·2 cm^3. This would indicate that the results of the water displacement method are within four per cent of the mean approximately two-thirds of the time. Consequently, it was arbitrarily decided that a difference between the results of the monophotogrammetric method and the water displacement method of less than four per cent would represent ‘ substantial agreement ’ between the methods.

§ 3. Results and Discussion

The total volume of the model was 947·2197 cm^3 when determined by the photogrammetric method. This results in a difference of 1·79 per cent when compared to the mean of the water displacement method and indicates a substantial agreement between the two methods. The areas of the various isopleths of Fig. 2 are shown in the Table.

Areas of the Isopleths of Fig. 2 (in cm^2)

Isopleth	Area	Isopleth	Area	Isopleth	Area
0	18·8152	7	242·3657	13	257·9752
1	46·2270	8	262·7127	14	65·2658
2	70·8814	9	277·6740	15	126·7857
3	103·5647	10	302·7130	16	86·5700
4	133·5717	11	302·9588	17	16·0548
5	177·5543	12	284·8214	18	0·6296
6	212·5156				

Although not quite as accurate as stereophotogrammetry, the method of volume determination by monophotogrammetry described in the present study probably is as accurate, if not more so, than the commonly-employed water displacement and formulae methods. In addition, it has the advantage over other methods of being less expensive, not requiring skilled personnel for the collection, collation, and interpretation of the data, and of being less time- and space-consuming. One disadvantage of the monophotogrammetric method also inherent in water displacement methods) is that the resulting volume

figure represents the entire volume encompassed by the skin and gives no indication of the amount attributable to abdominal gases or residual air. The upper limits of gas in the G-I tract have been estimated at 0·05 to 1 l. by Keys and Brozek (1953), and Marshall *et al.* (1955) found the abdominal gas volume normally to be 115 ml. Von Döbeln (1956) felt that errors in density figures as a result of variations in abdominal gases are so minute that there is little reason to correct for them. Where specific gravity and other correlates of body volume are to be made, residual air may be estimated by the technique of Willmon and Behnke and any of the standard methods employing spirometry.

L'auteur décrit une méthode de détermination du volume corporel par monophotogrammétrie. Des comparaisons entre le volume obtenu à l'aide de cette méthode et celui obtenu par déplacement d'eau montrent une différence de 1,79 pour cent. Ceci répresente un accord satisfaisant et, en outre, la méthode monophotogrammétrique élimine les inconvénients majeurs des méthodes de déplacement d'eau, de pesée hydrostatique et d'évaluation à l'aide de formules.

Eine Methode zur Bestimmung des Körpervolumens mit Hilfe der Monophotogrammetrie wird beschrieben. Der Vergleich des Volumens, das mit dieser Methode bestimmt wurde, mit dem mit der Wasserverdrängungs-Methode erhaltenen Volumen ergab einen Unterschied von 1,79 Prozent. Das bedeutet "Praktische Uebereinstimmung", zumal die monophotogrammetrische Methode die grösseren Nachteile von Methoden vermeidet, die mit Wasserverdrängung, mit hydrostatischer Wägung oder mit Formeln arbeiten.

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THE OPTIMUM SIZE AND SHAPE OF CONTAINER FOR USE BY THE FLOWER BULB INDUSTRY

By F. T. Kellermann and P. A. van Wely

Philips Ergonomics Group, N. V. Philips' Gloeilampenfabrieken, Eindhoven, Holland

This article deals with an investigation into the optimum size and shape of a container for transport and storage of bulbs in the Dutch flower bulb industry. A long and narrow container proves to be more serviceable than a short, wide one. Taking into account the conditions prevailing in the bulb industry whereby temporary unskilled labour is widely used, a weight of 17·5 kg for a fully laden container is physiologically optimum.

§ 1. Introduction

The Netherlands Economic Technological Institute (E.T.I.), with a view to increasing productivity, carried out an investigation into working methods in the flower bulb industry. During the investigation it was found desirable to use a uniform container for the transport and storage of the bulbs. The N. V. Philips' Gloeilampenfabrieken showed an interest in this project and were asked whether they would be able to market such a container which would have to be made of plastic. The Philips Ergonomics Group (P.E.G.) was accordingly requested to determine the shape and size of such a container from the working efficiency and physiological points of view.

§ 2. The Processes of Bulb Handling

In the Netherlands there are approximately 8000 growers of flower bulbs, some of whom carry on an export business of their own. Since the growing of flower bulbs is a very old industry in the Netherlands, it is readily understood that there exist many traditional practices and that various packing methods are used. During visits to some of these firms it became clear that the indiscriminate use of a large variety of baskets, crates and cases, sometimes within one firm (see Fig. 1), and the transport of such a mixture of containers must inevitably lead to inefficient handling.

In one of the firms the work routine for the production of tulip bulbs was studied. The processes may be summarized as follows :

1. The bulbs are lifted into *small baskets* or *containers* which can hold approximately 10 kg.
2. The bulbs are sieved in the field, during which operation most of the soil is separated from the bulbs. They are then dumped into *auction baskets* (capacity 50 l., approximately 35 kg).
3. The bulbs are transported to the shed.
4. On arrival in the shed the bulbs are removed from the baskets and dumped into *gauze containers* or *racks*, where they are left for a few days to dry.
5. The bulbs are scooped from the racks into auction baskets after which they are carried to the peeling room. The bulbs may be carried in the gauze containers, instead of being transferred to baskets.

Figure 1. Transport by a mixture of containers.

6. The bulbs are dumped on to tables and peeled. After peeling, the bulbs are dumped into auction baskets.
7. The baskets with peeled bulbs are carried to the sorting machine.
8. The bulbs are passed over a sorting belt, during which the unsuitable bulbs are sorted out, after which they are mechanically sorted according to size.
9. The bulbs are collected in auction baskets.
10. The smallest sizes of bulbs, i.e. those to be planted out, are dumped into gauze containers or on to racks and remain thus stored till the planting season arrives.
11. The large sizes are considered marketable and are :
    (*a*) carried to the auction to be sold there, or
    (*b*) dumped into gauze containers or on racks and stored for the time being to dry more thoroughly.
12. The marketable bulbs are taken out again. If the bulbs are lying on racks they are first scooped into baskets, after which they are carried to the working room. If the bulbs are stored in gauze containers they are carried to the working room in these containers.
13. The bulbs are counted mechanically or by hand and put into *paper bags* each containing 100, 200 or 250 bulbs. In as far as the bulbs are destined for private persons, they are sometimes packed in *boxes* as well.
14. If there is a shortage of marketable bulbs grown by the firm itself, additional bulbs are bought at the auction. These bulbs arrive in auction baskets and are counted and packed into paper bags.
15. The bags and boxes are put on the racks again.

16. When the export season has arrived, the marketable bulbs are collected per order and packed in *cases* or boxes and are so despatched to the customers.
17. The bulbs to be planted out are carried to the breeding fields in baskets in October, November and December to be planted out again.

The larger part of this work is performed in the summer months of July and August; consequently very much seasonal work is done in the industry by *untrained* secondary school children, students and other temporary personnel, e.g. housewives. Manual transport is used on a more or less extensive scale at all the stages mentioned above ; if the distances to be covered become too great, flat wagons are used. Pallets are occasionally used but only by a limited number of bulb growers.

§ 3. The Requirements of the Container

During the visits to the bulb-growing industry the requirements of the container were drawn up on the basis of discussions with bulb growers and the investigators of the E.T.I.:

3.1. *Weight*

(*a*) The auction standard of 50 l. (approximately 35 kg gross) must be maintained, so that the container must have a *content* of 50 l., or such a part thereof that it can be *readily divided*;

(*b*) the work must be such that the largest portion can be done by scholars and students, i.e. untrained people (both boys and girls).

3.2. *Shape*

(*a*) It must be possible for the bulbs to dry thoroughly *in* the container. For this reason the depth of the container must not be greater than approximately 12 cm (loaded to a depth not greater than approximately 10 cm), while the container must be liberally provided with ventilation holes;

(*b*) it must be possible to stack the containers and to place one inside the other for storage.

§ 4. The Investigation

The *optimum weight* and the *optimum shape* were studied as separate factors. Eighteen volunteer subjects were chosen from our own colleagues (doctors, office clerks, etc.). None of the subjects was trained for this type of work, the average age was 41·5 years and all were in good health. The tests were carried out in the Philips Health Centre with the collaboration of Mr. van Vonderen, Technical Assistant.

4.1. *Weight*

As regards to the weight, a few data may already be found in the labour physiological literature. Lehman and Spitzer, amongst others, have already stated that a weight of 20–25 kg lifted by both hands gives a maximum of efficiency, i.e. a minimum use of energy per kilogram-metre of work actually performed.

In accordance with the wishes expressed by the bulb-growing industry (see § 3.1) three weights were compared, viz. : 35 kg, 17·5 kg and 8·75 kg. The influence of shape was eliminated by presenting these different weights to the subject in the same shape auction basket.

The subjects were given the task of carrying 210 kg of flower bulbs over a distance of 12 m, i.e. in lots of 35 kg (6 times), 17·5 kg (12 times) and 8·75 kg (24 times). This could always be done within five min. The sequence of the experiment was varied from subject to subject so that any fatigue phenomena were randomly distributed over all three weights.

Figure 2. The "heartnik".

The heart-rate was used as an index of work-load. It was recorded continuously during each experiment with the aid of the 'heartnik'. This instrument (Fig. 2) consists of a small radio transmitter which emits a signal with each heart-beat. The pulsations are picked up from the lobe of the ear by a photo-cell and transistor amplifier. In this way the subject is not hampered in his movements. He only wears the small transmitter and the

ear clamp. The heart-beat is recorded at a distance with the help of a radio receiver (Fig. 3).

For all subjects the heart-rate followed a similar course in each experiment and had the appearance shown in Fig. 4, recorded over a 5-min period. The average of the heart-beat frequency in these 5 min for each of the three loads yielded three results for each subject, enabling comparison of the effect of the load to be made by use of Friedman's test (method of the *m* arrange-

Figure 3. Recording the heart rate.

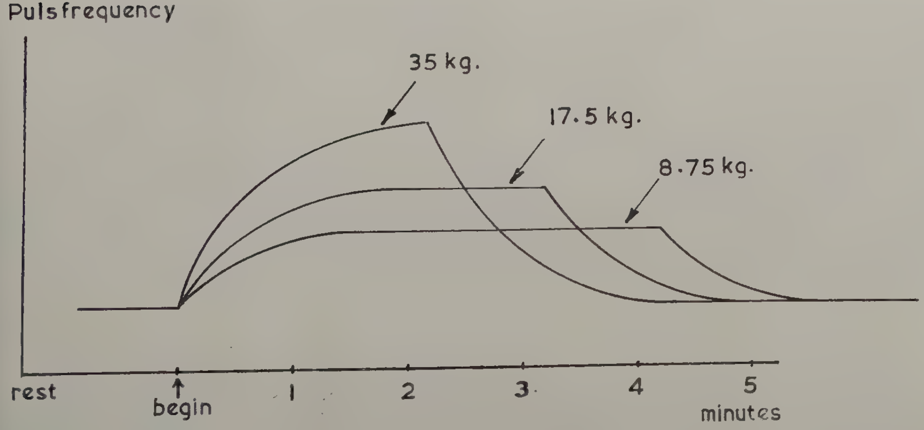

Figure 4.

ments). The difference between the three loads was statistically highly significant at the 1 per cent level (Table 1).

Table 1. The Friedman test on averages of pulse-frequencies over 5 minutes during the carrying of different loads

Subject No.	Weight in kg			Rank			
	8·75	17·50	35·00	8·75	17·50	35·00	
1	121·6	115·7	113·9	3	2	1	
2	128·4	140·8	135·6	1	3	2	
3	140·0	132·6	139·3	3	1	2	
4	135·8	120·7	122·8	3	1	2	
5	148·7	142·5	133·6	3	2	1	
6	170·4	167·6	152·6	3	2	1	
7	131·9	126·5	124·8	3	2	1	
8	104·2	112·7	105·4	1	3	2	
9	114·4	112·0	116·0	2	1	3	
10	114·4	111·4	112·6	3	1	2	
11	148·4	136·4	125·3	3	2	1	
12	121·0	110·8	107·8	3	2	1	
13	150·5	144·7	146·4	3	1	2	
14	113·6	113·2	108·6	3	2	1	
15	150·9	136·5	144·5	3	1	2	
16	117·3	112·0	110·4	3	2	1	
17	134·9	138·2	129·5	2	3	1	
18	113·8	105·8	98·5	3	2	1	
$n=18$ subjects	$Sj=$sum of ranks			48	33	27	108
$k=3$ different	$S=$expected sum of ranks.			36	36	36	108
weights	$Sj-\mathbf{S}$:			+12	−3	−9	0

$K_0=(Sj-\mathbf{S})^2=(+12)^2+(-3)^2+(-9)^2=234$

$$\chi^2_0=\frac{12\,K_0}{nk\,(k+1)}=\frac{12\times 234}{18\times 3\times 4}=13{\cdot}000 \text{ (2 degrees of freedom)}$$

For $P=0{\cdot}01$ $\chi^2=13{\cdot}815$ (5 per cent point is 10·597)

It is thus obvious that the weight of 8·75 kg gives rise to the highest average heart-beat frequency, i.e. the least favourable result. There is less difference between 17·5 and 35 kg, the lowest heart-rates being found for 35 kg. Consequently this would be the most favourable weight, if it were not for the fact that, during the carrying of this weight, the heart-rate reached high values with most subjects and showed a tendency to increase throughout the task instead of reaching a steady state. For this reason, especially in view of the many untrained young people of school age employed in this work, it was decided to accept the weight of 17·5 kg as the optimum. A trained and experienced man could, however, carry two stacked containers each of 35 kg if required.

4.2. *Shape*

It is possible of course to have 17·5 kg carried in all kinds of shapes. Account must be taken, however, of the practice of the bulb-growing industry in the choice of shapes for experimental study. Thus three models of container were decided upon (Fig. 5) ; one was closely similar to the gauze container,

the second to the 'Antha' crate, both of which are widely used. The third container was long and narrow and had dimensions such that, when pallets are used in the drying sheds, the container ensures maximum loading efficiency

Figure 5. The three different shapes of container used in the experiments—L, left; M, K, right.

with four containers in one layer. The dimensions of the three containers are stated in Table 2.

Table 2

	Internal dimensions K	L	M	External dimensions K	L	M
Length	360	860	510	500	1000	650
Width	350	300	450	350	300	450
Height in mm	190	120	120	260	190	190

It can be argued that the long container L is to be preferred to the medium sized and short ones, since it offers the advantage of enabling the worker to carry it with stretched arms, without causing too much trouble for the upper leg. For if the side of the container rests against the upper legs when being carried this will hinder the bearer very much and will constitute an extra load for the upper legs or for the arms if the container is lifted up away from the legs.

Furthermore container L offers the advantage that, due to its small width, its centre of gravity will be close to the axis of the body, so that it is not strictly necessary to lean the body backwards for maintaining the equilibrium. Container L has been compared with containers K and M in the next test. Twelve subjects were chosen, in general untrained, with an average age of

30 years. Each subject carried the containers loaded to the same weight, in varying order, over a distance of 360 m at a constant speed (90 m/min). In all tests the heart-rate reached a constant level, i.e. a steady state, after 1 to 2 min ; the average frequencies during carrying were used as an index of the work-load. After the test the subjects were asked which container they thought most convenient for carrying (see Table 3).

Table 3. Wilcoxon's matched-pairs signed-ranks test on averages of pulse-frequencies over 4 minutes during the 'shape-experiment'

Subject No.	Order	Preference	L	K	K–L	Rank	Signed rank	
1	L.K.	L	156·8	165·8	+9·0	9	+9	
2	K.L.	L	113·0	117·9	+4·9	4	+4	
3	L.K.	K	126·4	133·2	+6·8	6	+6	
4	L.K.	L	130·6	128·8	−1·8	3	−3	
5	K.L.		109·8	108·3	−1·5	1	−1	
6	K.L.	L	101·4	108·2	+6·8	5	+5	
8	K.L.	L	113·0	120·1	+7·1	7	+7	
9	L.K.		129·0	151·7	+22·7	11	+11	
10	L.K.		113·4	111·7	−1·7	2	−2	
11	K.L.		122·7	130·3	+7·6	8	+8	
12	L.K.	L	105·1	114·5	+9·4	10	+10	
(7 did not perform K)								
$n=11$						66	54 = V	P=0·01
			L	M	M–L			
2	L.M.		113·0	117·0	+4·0	6	+6	
3	M.L.		126·4	130·3	+3·9	5	+5	
4	L.M.		130·6	129·7	−0·9	2	−2	
5	M.L.	M	109·8	112·8	+3·0	3	+3	
6	M.L.		101·2	106·2	+5·0	8	+8	
7	M.L.	L	136·5	140·1	+3·6	4	+4	
8	L.M.		113·0	125·1	+12·1	11	+11	
9	M.L.	M	129·0	140·3	+11·3	10	+10	
10	L.M.	M	113·4	113·1	−0·3	1	−1	
11	M.L.	M	122·7	127·3	+4·6	7	+7	
12	L.M.		105·1	112·1	+7·0	9	+9	
(1 did not perform M)								
$n=11$		L:7 M:4 K:1	control sum of ranks $\frac{n(n+1)}{2}=\frac{11\times 12}{2}=66$			66	60 = V	P=0·01

The hypothesis that the long container L gives most favourable results was found to be correct at a probability level of 1 per cent. As regards personal opinion, 7 out of the 12 subjects preferred the long container. An interesting fact was that no difference whatsoever could be demonstrated between containers M and K.

4.3. *Other considerations*

To facilitate further the carrying of the container, the use of a strap round the neck was advised. The hooks fitted to the strap can be slung through the handles of the container. The standard container can be transported on

pallets. With this in view the outside dimensions of the container were chosen so that the surface of the pallet is utilized as fully as possible (pallet dimensions 100×120 cm). Stacking of the containers was also considered desirable.

§ 5. Conclusions

From these investigations (both from the working and psychological point of view) the following conclusions can be drawn :

1. The optimum weight for untrained people is 17·5 kg (25 l. content) taking into account the requirements mentioned in § 3.1.
2. The optimum dimensions are $100 \times 30 \times 12$ cm (external dimensions), thereby permitting four containers to be placed on a pallet in one row.

The prototype in accordance with the foregoing requirements was designed by the styling department (Fig. 6).

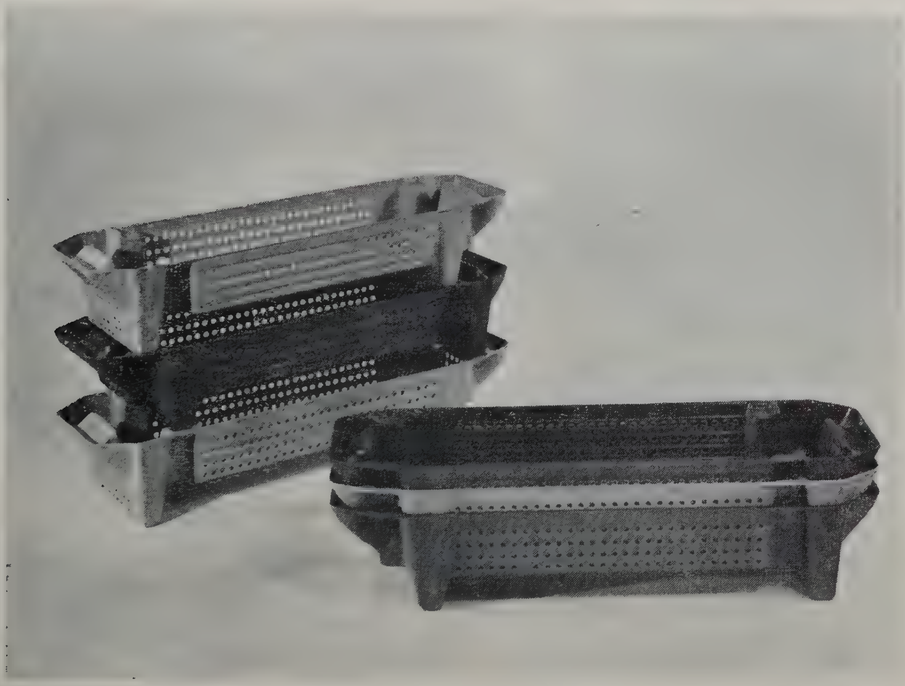

Figure 6. The uniform container.

Il s'agit d'un examen effectué par le ' groupe ergonomique Philips ' ayant pour but de déterminer poids et forme optimales d'un récipient pour les besoins de transport et d'entreposage d'oignons de tulipe dans les entreprises néerlandaises. Compte tenu des données statistiques et étant donné les circonstances particulières qui règnent dans la culture des oignons de tulips on peut conclure de cet examen qu'un poids de 17,5 kg doit être considéré physiolique comme optimale, et qu'un forme longue et étroite vaut mieux qu'une forme courte et large.

Eine Untersuchung der ' Philips Ergonomischen Gruppe ' über das optimale Gewicht und die geeignetste Form einer Verpackung für den Versand und die Lagerung im niederländischen Blumenzwiebelgewerbe. Diese Untersuchung führt zu den statistisch vertretbaren Schlusz, dasz, unter Berücksichtigung der Verhältnisse im Blumenzwiebelgewerbe, das Gewicht von 17,5 kg physiologisch optimal ist. Ein langer, schmaler Behälter ist günstiger als ein kurzer breiter.

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A LABORATORY COMPARISON OF TRACKING WITH FOUR FLIGHT-DIRECTOR DISPLAYS

By I. D. Brown, S. D. Holmqvist and M. C. Woodhouse

Medical Research Council, Applied Psychology Research Unit, Cambridge

The following flight-director displays were compared in the laboratory on a simple aircraft simulator under controlled conditions of noise and ambient illumination: (*a*) *Streaming Lights* which presented errors in the flight of the ' aircraft ' by the direction and rate of apparent movement of streaming lights; (*b*) ' *Barber's Poles* ' which presented errors by the direction and rate of translational movement of a white helical strip along a black, rotating pole; (*c*) *Flashing Lights* attached to the simulator, or to a helmet worn by the subject, which presented errors in each dimension by the position and rate of flash of a single flashing light; (*d*) *I.L.S. Meter* which was intended to represent a Zero-Reader display and presented errors by the position of two pointers mounted at right angles to each other. All these displays were designed to present navigational information to a pilot while he was scanning the outside world, and all except the last presented the information in peripheral vision.

In continuous tracking, the time off target with Flashing Lights or the I.L.S. Meter was about a quarter of the time off target with either the Streaming Lights or the Barber's Poles. In correcting sudden errors, Flashing Lights on the Helmet gave quicker responses than any other display which was investigated. This was presumed to be the result of the high attention-getting value and the immediate directional indication of the signals. The weakness of Flashing Lights on the Helmet, which also applied to the Barber's Poles and Streaming Lights, was in presenting information on the size of errors. The I.L.S. Meter was the best display in this respect, although it did not always attract the man's attention as soon as it indicated an error. The combination of Flashing Lights on the Helmet and the I.L.S. Meter produced the quickest corrections recorded during the experiments.

Reaction time to signals presented on a central display increased about 40 per cent when attention had to be paid to any of the flight-director displays. The size of the increase was about the same whether simulated control of the aircraft was carried out or not while performing the central task. This suggests that it was the need to attend to the additional channel of information, rather than simultaneous demands for action, which interfered with the central task.

Performance with Flashing Lights on the Helmet and Streaming Lights showed only a small and not statistically significant adverse effect from occasional rotation of the head and eyes of 70°.

Sideways movements of the head altered the angle subtended at the subject's eye by the Barber's Poles mounted horizontally fore and aft to display information on altitude. This changed the apparent rate of movement of the display and the apparent display-to-control ratio, and thus caused the subject to miss small errors occasionally, or make control movements of the wrong size. In addition, with the Barber's Poles the display-control directional relationships changed as attention was directed from one end of the azimuth display to the other. This could occur in an aircraft when the pilot rotated his head and eyes, and might be dangerous.

§ 1. Introduction

When an aircraft is fitted with the ' Instrument Landing System ' (I.L.S.) type of equipment, errors in altitude and bearing are displayed on a ' crossed-pointer ' instrument, as shown in Fig. 1, which is placed below the windscreen of the cockpit. During an approach to land, the pilot's task becomes one of maintaining the two pointers crossed over the exact centre of the dial of the instrument, in order to achieve the correct glide-path. As the I.L.S. does not function accurately down to ground level, the actual touch-down requires visual perception of the outside world. Under conditions of poor visibility there is usually a transition period during which the pilot must alternate

between tracking the I.L.S. instrument and searching the outside world. During this period, eye movements and changes in accommodation are wasting a high proportion of the total scanning time. The stress produced by this searching would be considerably reduced if errors in altitude and bearing could be perceived by the pilot while he was looking towards the point at which the runway was expected to appear. Four alternative methods of presenting

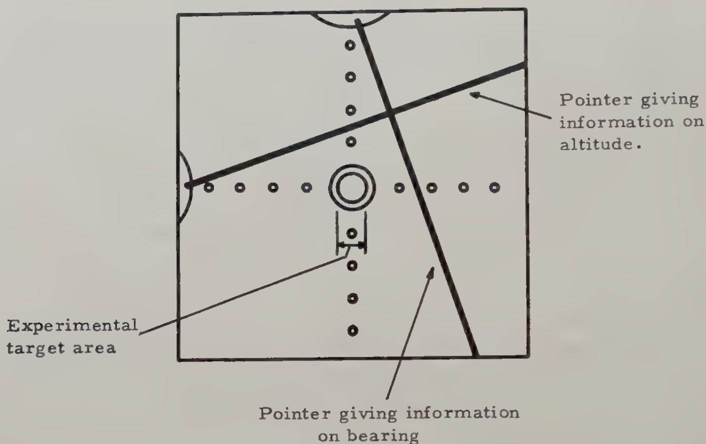

Figure 1. The I.L.S. Meter Display.

information in this way have been suggested, three of which make use of peripheral vision. Experiment I compared the performances of naïve subjects when the different displays were used in a simulated aircraft and the task was continuous compensatory tracking. The principal criterion of efficiency was 'time-off-target' in a test period of ten minutes.

The installation of an automatic pilot relieves the man of the necessity of controlling his aircraft all the time. However, in flying at low altitudes the man needs an immediate directional warning if the autopilot fails, particularly if the aircraft starts to lose height, so that the correct control movements can be made immediately manual control is assumed. Experiment II compared four methods of displaying the sudden errors in bearing and altitude which might be caused by failure of the autopilot. The principal criterion of efficiency was the time taken to correct the errors. With two of the display systems, the effect upon performance of rotating the head and eyes, which may occur while scanning the ground, was also investigated.

In Experiment III, combinations of some of the alternative display systems were compared. The ideal single or combined display must attract the attention of the pilot as rapidly as possible and must also present clear information on the size and direction of the error. These qualities were not possessed in equal measure by all the alternative systems which were compared. The object of this third experiment was to determine whether a combination of two display systems would lead to a more rapid correction of errors than either display alone.

In all three experiments the subject fixated a central display which presented, at irregular intervals, signals which had to be reacted to as quickly as possible.

A third criterion by which the flight-director display systems were compared was the extent to which reaction time to this central task was increased when errors in altitude and bearing had to be detected while performing it.

§ 2. Experiment I. Continuous Tracking

2.1. *Apparatus*

The simulator. The various displays were attached to a hemispherical framework of 30 in. radius. A chair was placed so that the eyes of a seated subject were approximately at the centre of the hemisphere. A control column was arranged in front of the chair, to be operated by the right hand. A relay was placed on the left of the control column. The subject operated this with his left thumb in response to signals from the central display. The framework of the simulator was surrounded by a curtain to provide a matt-black background to the displays. A front view of the hemisphere is shown in Fig. 2.

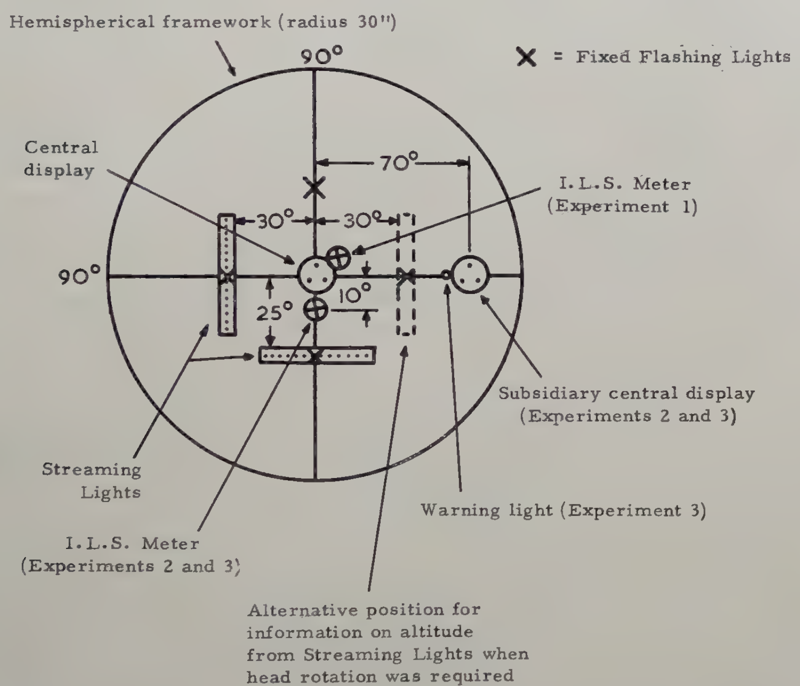

Figure 2. The framework of the simulator showing the layout of the displays. The angles shown were subtended at the subject's eye by the centre of the curved framework of the hemisphere and displays attached to the framework.

The central task. The display for this consisted of a ground glass screen, of 6 in. diameter, placed at the centre of the curved surface of the hemisphere (see Fig. 2). Three spots of light, each 0·75 in. in diameter, were arranged at the corners of an equilateral triangle of side length 2 in. The spots of light were projected from behind on to the screen by 2-watt filament lamps. Each lamp was switched on or off separately, in a prearranged order, by an experimenter in the first instance and later by an automatic programming device. In either case the same result was produced on the display. The central display was

changed by adding or removing one spot at a time. The central task was to press the relay with the left thumb, as quickly as possible, whenever the display changed. In order to provide a fixation point for the subject at all times, the display did not show less than one spot. Each change in the central display started a dekatron timer which was stopped by the subject's response. Changes which were not responded to within 3 sec were recorded as ' missed signals '. The timer was stopped automatically in these cases. Post Office counters scored the number of changes which occurred and the number of signals which were missed.

2.2. *The Display Systems*

(i) *Streaming Lights.* This display consisted of two rows of neon indicator lamps, type CC3L. Each row was 21 in. long and contained 48 lamps spaced at equal intervals. The lamps were connected to a 200 v supply through a series resistor of 470 K. ohms. One row was placed below the central display (see Fig. 2). The vertical interval between this row and the central display subtended an angle of 25° at the subject's eye. This row of lamps was used to present errors in bearing. The second row was placed vertically to the left of the central display and was used to present errors in altitude. The horizontal interval between this row and the central display subtended an angle of 30° at the subject's eye. A gap was left between the ends of the two rows of neon lamps to prevent the two displays from being apprehended as a single complex display. Eight lamps in each row were illuminated at any instant. Signals were presented by the apparent streaming movements of the lamps. These were produced by rotating a commutator having 48 segments, one lamp being attached to each segment. The commutators could be driven at different speeds, in either direction, by velodyne motors. The direction of the streaming movements in the two rows of lamps indicated the direction of the required control movement, and the rate of streaming indicated the size of the movement.

Errors in altitude and bearing were introduced into the system by two cams. These were driven at a constant speed of one revolution in 280 sec. Each cam produced four reversals of the course per revolution but, apart from this, the shape was quite arbitrary. The cams operated two potentiometers. Two similar potentiometers were attached to the control column at right angles to one another. The four potentiometers were built into bridge networks. Movements of the cams produced difference voltages which were amplified to drive the velodyne motors in clockwise or anti-clockwise directions. The consequent rotation of the commutators produced streaming effects on the neon lamp displays. These could be reduced to zero by moving the control column until the bridge networks were again in balance. There was a linear relationship between the rate of streaming and angular displacement of the control column. In this, and all subsequent flight-director display systems to be described, the tracking task was compensatory, with zero time lag.

A dead space of 2° was allowed, within which movements of the control column did not affect the display. A streaming rate of up to ± 3 in. per sec was denoted as the ' target area '. This was equivalent to an angular displacement of the control column of $\pm 7°$. These limits were used in fixing the target area with all subsequent flight-director displays. When errors

exceeded these limits, electronic trigger devices were operated which were connected to two dekatron timers, one of which summed ‘ time-off-target ’ in altitude and the other in bearing.

The control column was 4 in. long and moved without spring loading. Friction was negligible. Streaming movements to the left were nulled by control movements to the left. Streaming movements upwards were nulled by control movements towards the subject.

(ii) *I.L.S. Meter.* In future aircraft, the flight-director display which the I.L.S. Meter was intended to represent will be projected on to the windscreen. The projection will be collimated and thus visible to the pilot even when he is searching for the runway, or some other distant external feature. In the simulated aircraft the I.L.S. Meter itself was used. It was attached to the hemispherical framework to the right and slightly above the central display (see Fig. 2). The centres of the two displays were separated by an interval which subtended an angle of 6° at the subject's eye. The central display and the face of the I.L.S. Meter were in approximately the same focal plane. The face of the meter was illuminated by a small shielded lamp. The two pointers were operated by the same out-of-balance bridge potentials which were used to deflect the Streaming Lights. As before, errors in altitude and bearing could be corrected by means of the control column. When the horizontal pointer moved above the centre of the dial, the correct control movement was towards the subject. When the vertical pointer moved to the left of the centre of the dial, the correct control movement was to the left. Operating conditions with the Zero-Reader type of equipment were simulated. The target area was a white circle of approximately 5/16 in. diameter on the face of the meter.

(iii) *Fixed Flashing Lights.* Four neon lamps, of the same type as those which were described in ‘ Streaming Lights ’, were attached to the hemisphere. Two lamps displaying errors in altitude were placed vertically above and below the central display (see Fig. 2). The interval between each of these lamps and the central display subtended an angle of 25° at the subject's eye. The other two lamps, which displayed errors in bearing, were placed horizontally to the left and right of the central display. The interval between each of these two lamps and the central display subtended an angle of 30° at the subject's eye. A flashing light to the left of the central display indicated a control movement to the left, and a flashing light above the central display indicated a control movement towards the subject. The rate of flashing indicated the size of the movement. ‘ Flashing ’ was obtained by the use of the two commutators which were described previously. When the system was balanced exactly at the null point, the lamps were not illuminated. As an error was introduced into the system, the lamps commenced to flash at approximately 60 flashes per min. Time-off-target was recorded when the flashing rate exceeded 150 flashes per min.

(iv) ‘*Barber's Poles*’. This display consisted of three black tubes which were arranged in front of the subject as shown in Fig. 3. Each tube was painted with a white helix and was driven by a motor. Rotation of the tube produced an illusion of translational movement the direction of which depended upon the direction of rotation of the tube. The display was assembled in a

black metal case which incorporated flood lighting of adjustable brightness, and was viewed through a perspex window. The pole which presented changes in bearing was mounted horizontally below the central display (see Fig. 3). Two other poles were mounted horizontally 'fore-and-aft', one on each side of the first pole, to present changes in altitude. In all other respects the operation of the Barber's Poles was the same as that of the Streaming Lights.

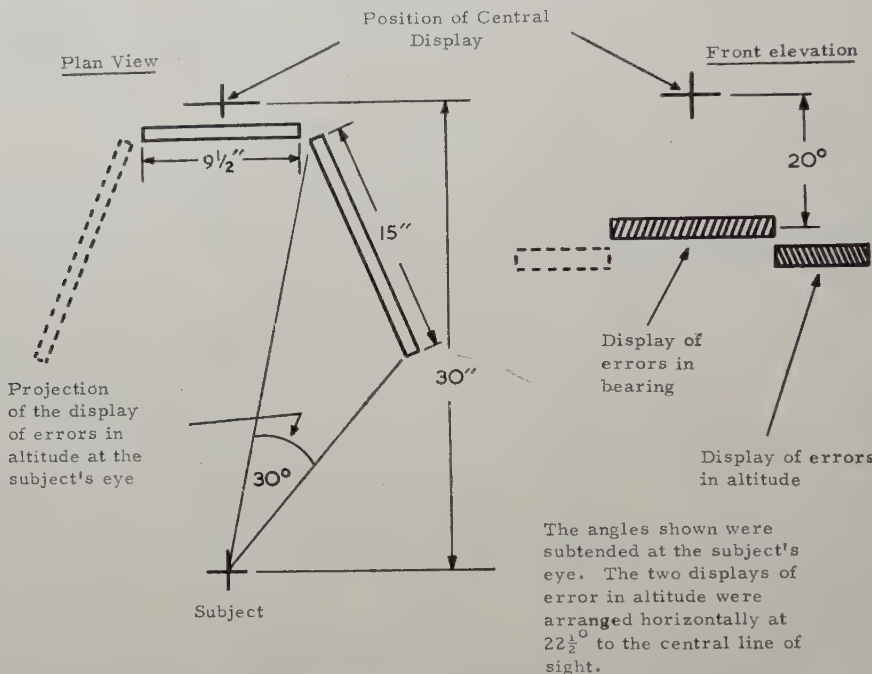

Figure 3. Arrangement of the Barber's Poles in the far position.*

* For half the subjects, only the right hand pole was used to display errors in altitude in this arrangement.

2.3. *Subjects and Procedure*

The subjects were 34 naval ratings whose ages ranged from 17 to 26 years (median age 19). All but one had normal uncorrected vision. The other subject was far-sighted and wore spectacles during the experiment. Two subjects were left-handed but found the right-handed control column satisfactory for tracking. Their 'on-target' scores did not appear to be significantly different from the scores of the other subjects. The subjects were divided into four groups, each assigned to one of the display systems.

The subject wore a helmet fitted with earphones, through which approximately 'white' noise was presented at a sound pressure level of about 75 dB to mask the noise of the apparatus. The test was performed in complete darkness except for the illumination of the displays.

On the first day, the subject was introduced to the apparatus and given 10 min initial practice. On each of the following four days there were three 10 min trials. In one trial the central task was performed alone and in the

other two trials the central and the tracking tasks were performed simultaneously. The subject had to fixate the central display and perform both tasks as efficiently as possible. Because reaction times tended to lengthen during the three successive trials on any one day, the central task was on different days presented alone before, between and after the combined tasks. When the central task was performed alone, the flight director display showed an error which was equal to the limit of the 'on-target' area. For example, the Streaming Lights moved at 3 in. per sec. Thus any distracting effect of the display was included in the measure of normal reaction time. Any increase in reaction time when the flight-director display was used, was therefore considered to result from having to perform this additional task.

The scores of all subjects for 'time-off-target', 'mean reaction time' and 'mean reaction time while tracking', were plotted graphically after the first day. On the following days each subject was shown his own learning curves and could see also curves for all the other subjects of that week. Equal emphasis was placed upon scores for tracking and reaction time to avoid biasing the subject towards one or other of these tasks. The number of missed signals on the central task was stressed at the end of each trial in order to encourage the subject always to fixate the central display.

With all displays except the 'Barber's Poles', the subjects followed a similar procedure during a second week of testing, but were trained in the use of another display system. All subjects who were trained in the use of either the I.L.S. Meter or the Fixed Flashing Lights received training on the Streaming Lights during their second week. The subjects who were trained on the Streaming Lights in the first week were divided into two groups, one of which was trained on the I.L.S. Meter in the second week and the other on the Fixed Flashing Lights.

2.4. *Results*

(i) *Transfer of training in tracking.* Errors in altitude and bearing were summed to give a score for 'time-off-target' in each trial. Each of these scores was thus the time in seconds for which the simulated aircraft was off course out of a total of 1200 sec. The mean learning curves for each group of subjects are shown in Figs. 4 and 5. Figure 5 shows that there was considerable transfer from Fixed Flashing Lights to Streaming Lights at the start of the second week. Figure 4 shows that there was considerably less transfer from the I.L.S. Meter to Streaming Lights. The transfer presumably depended upon similarities between the two displays. Unfortunately, it precluded the pooling of scores from the first and second weeks, since subjects who worked with Fixed Flashing Lights in the first week started in the second week with Streaming Lights at a more advanced level of training than subjects who worked for the first week with the I.L.S. Meter.

(ii) *Tracking.* Three trained pilots who tracked with the Streaming Lights and the I.L.S. Meter while performing the central task were able to achieve immediately the level of proficiency which was obtained by naval ratings after approximately five 10 min trials. The four display systems were therefore compared by considering scores which were obtained only after 50 min of training. These scores, which came from the last two days of testing in the first week, are shown in Table 1.

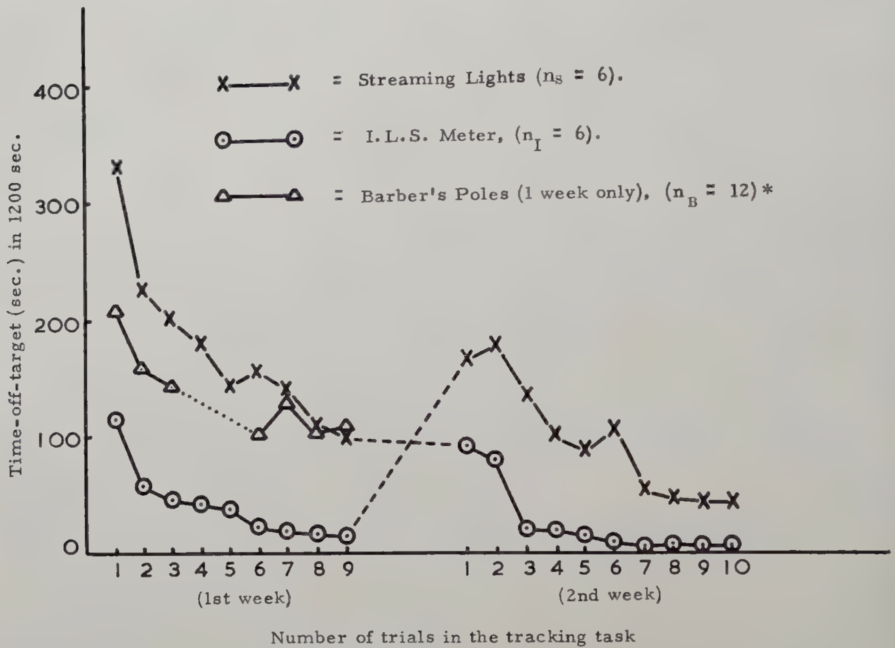

Figure 4. Mean scores of time-off-target when tracking the Streaming Lights, I.L.S. Meter, or the Barber's Poles.

* The raw scores with Barber's Poles on the third day of testing were lost before time-off-target was analysed.

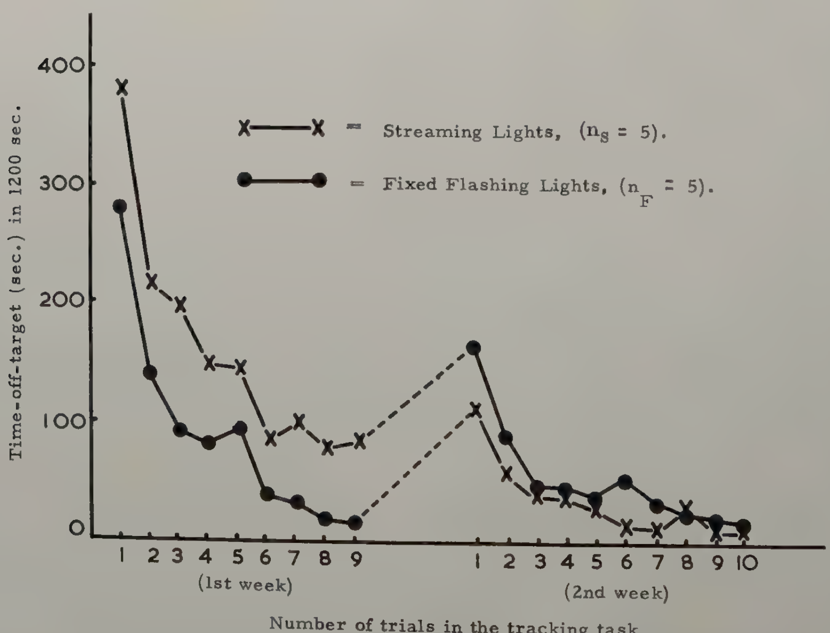

Figure 5. Mean scores of time-off-target when tracking the Streaming Lights or Fixed Flashing Lights.

Table 1. Scores on the continuous tracking task and the effect of divided attention upon the central task

	Type of Display			
	Streaming Lights	Barber's Poles	Fixed Flashing Lights	I.L.S. Meter
Number of subjects	11	12*	5	6
Tracking task: (Time-off-target in sec)				
Bearing: Mean	39·3	37·6	11·0	16·6
Altitude: Mean	69·3	71·5	15·0	2·7
Total: Mean	108·6	109·1	26·0	19·3
S.D.	57·8	79·6	10·1	11·4
Central task: Increase in reaction time (sec)				
Mean	0·15	0·088	0·19	0·12
S.D.	0·055	0·034	0·073	0·066
Missed signals: Mean	2·5%	1·9%	1·8%	1·9%
A.H.4 intelligence test				
Mean	80	70	80	80
S.D.	15·7	17·1	12·2	13·5

* Of the 12 subjects who used this display, 6 had the right-hand altitude pole only whereas 6 had both altitude poles. The differences between the scores of these groups were not significant ($P > 0·05$, Mann-Whitney test). The scores have therefore been pooled in the table.

The scores with the Barber's Poles did not differ significantly from the scores with the Streaming Lights ($P > 0·05$, Mann-Whitney test, see Siegel 1956, p. 116). Both these displays were significantly worse than either of the other two ($P < 0·01$), the scores on which did not differ significantly. With Streaming Lights and Barber's Poles, times-off-target in bearing were significantly shorter than times-off-target in altitude ($P < 0·01$, Wilcoxon test, see Siegel 1956, p. 75). The reverse was the case with the I.L.S. Meter ($P < 0·01$). The difference was not significant with Fixed Flashing Lights.

(iii) *Central task.* Reaction time to the central task alone did not vary significantly between groups of subjects ($P > 0·05$, Mann-Whitney test) and had a mean value of 0·35 sec. With all display systems, this was increased by about 40 per cent by the simultaneous performance of the tracking task. The increase with Barber's Poles was significantly smaller than with any other display ($P < 0·01$, Mann-Whitney test). However, the type of flight-director display had no significant effect upon the mean percentage of missed signals. The small percentages of missed signals with all four flight-director displays suggests that voluntary eye movements away from the central display were not common. If some subjects had looked fairly frequently at the flight-director display, instead of at the central display, a negative correlation might have been found between 'time-off-target' and 'increase in reaction time'. In fact the Spearman Rank Correlation Coefficient between these scores was +0·02 and was not significant. The instructions to fixate the central display continuously appear, therefore, to have been obeyed reasonably well.

(iv) *Individual differences.* The standard deviations of the 'time-off-target' scores shown in Table 1 indicate that individual differences were very substantial with Streaming Lights and Barber's Poles, but much smaller with the other displays. Also in Table 1 are shown the mean scores on the A.H.4

test of intelligence (Heim 1955). Unfortunately these scores became available only in the middle of the training period, and so could not be used to select groups of equal intelligence. The differences between the mean scores on A.H.4 of the various groups were not significant (Mann-Whitney tests), and it is clear that the mean A.H.4 scores were uncorrelated with the mean values of ' time-off-target ' and ' increase in reaction time '.

§ 3. Experiment II. Getting Back on to Course

Subjects were presented with errors in bearing and altitude which appeared suddenly while they were responding to signals from the central display. The time taken to correct the errors by appropriate control movements (' time for acquisition ') was measured. The effect of head rotation upon the time taken for acquisition with two of the displays was also tested.

3.1. *Apparatus*

The simulator was the same as that described in Experiment I. When head rotation was required, an alternative fixation point was provided by attaching a subsidiary ' central ' display horizontally to the right around the hemisphere from the main central display (see Fig. 2). The two displays were identical and were separated by an interval which subtended an angle of 70° at the

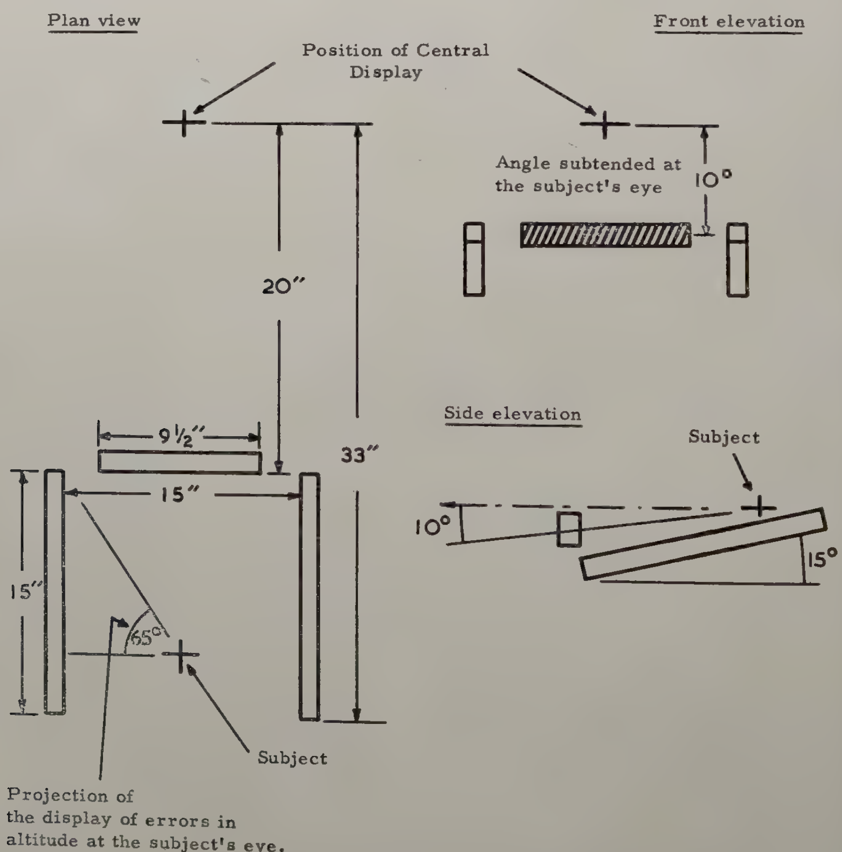

Figure 6. Arrangement of the Barber's Poles in the near position.

subject's eye. All changes of these displays were produced by an automatic programming device.

Step-function errors of five fixed sizes, obtained by using fixed resistors in place of the continuously-varying potentiometers of the previous experiment, were presented with each of the display systems except the Barber's Poles (see note to Fig. 8).

In order to avoid scoring as ' acquisition ' any accidental or intermittent control movements through the target area, the target had to be held for one second before the dekatron timers stopped.

In this experiment the I.L.S. Meter was not intended to represent a Zero-Reader reflected from the windscreen of the cockpit, but simulated the Zero-Reader on the instrument panel of an aircraft. It was therefore attached 10° vertically below the central display (see Fig. 2).

Two arrangements of the Barber's Poles were tested. One of these was identical with that shown in Fig. 3, where only the right-hand altitude pole was used. The other arrangement is shown in Fig. 6 and employed both altitude poles.

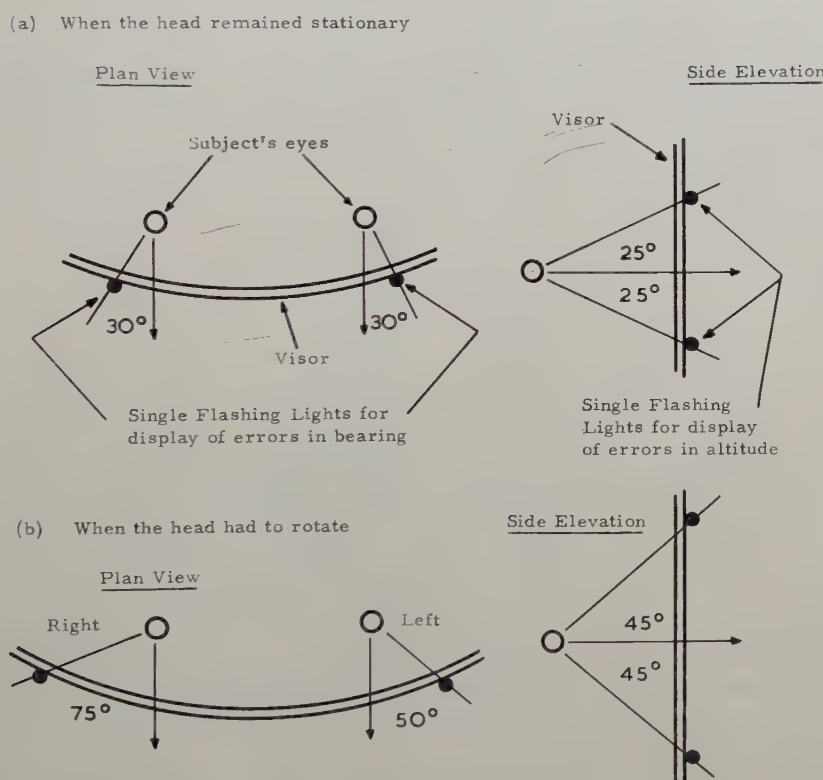

Figure 7. Position of Flashing Lights on the Helmet.

Flashing Lights were removed from the hemispherical framework and attached to a perspex visor which was fixed to the subject's helmet. The displacement of the lights from the central line of sight is shown in Fig. 7. The increased displacement when head and eye rotation was required (see Fig. 7 (b)) reduced the risk of confusion between information on bearing and

signals from the subsidiary central display, when the subject's eyes were rotated to the right. When the Streaming Lights were tested with head rotation, the vertical row of lights was placed in an alternative position 30° to the *right* of the central display (see Fig. 2). This enabled the errors in altitude to be seen when the subject was looking at the subsidiary 'central' display.

3.2. *Subjects and Procedure*

The subjects were 40 naval ratings whose ages ranged from 17 to 29 years (median age 21). All had normal uncorrected vision and had not taken part in previous experiments with this simulator. They were divided into six groups each of which performed under one set of conditions only.

The procedure was similar to that in Experiment I except that an overall low level of illumination was maintained by means of a shaded table lamp, and that the three training periods per day continued for 8 days after the introductory day. When the central task and the acquisition task were performed simultaneously, 40 errors were introduced into the flight-director system during an experimental period lasting 10 min. The time required to correct the errors was scored only on alternate trials, because every second trial was exactly the reverse of the first, and thus the direction and extent of the control movement could be predicted. Of the 20 control movements scored, half were made in response to changes in *either* altitude or bearing, and the other half were made in response to changes in *both*. The sizes of the changes were drawn systematically from the total range shown in Fig. 8.

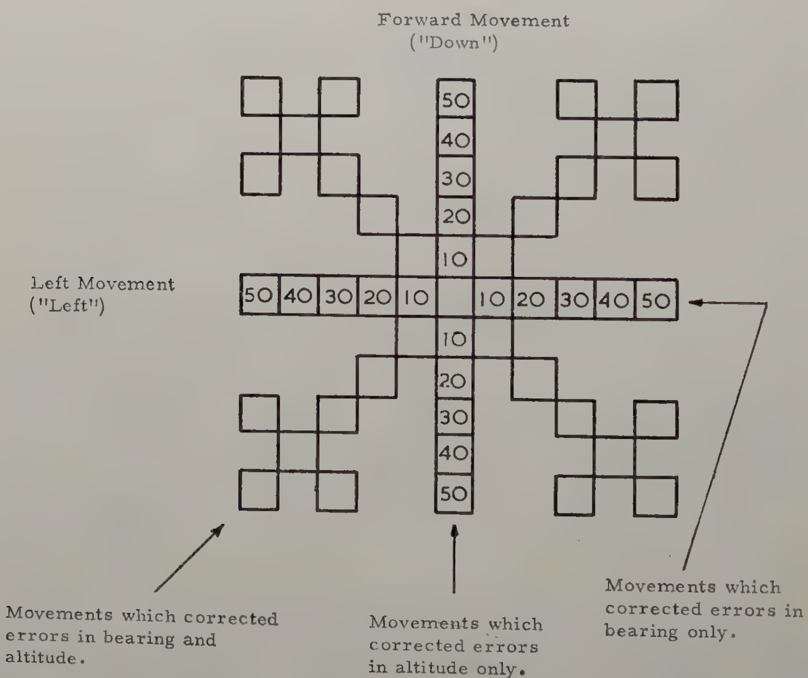

Figure 8. Sizes of control column movements, in degrees from the null position, required to correct errors in the flight-director displays in Experiments 2 and 3.

NOTE : With Barber's Poles, only the 4 largest sizes of error were presented, therefore control movements of 10° were excluded from this condition.

The Barber's Poles display was found not to be sufficiently sensitive to display the smallest size of error, which was therefore not used. The total number of signals presented in each experimental period remained, however, unchanged. One group of 6 subjects used the azimuth pole combined with only the right-hand altitude pole (see Fig. 3). A second group of 5 subjects used both altitude poles (see Fig. 6).

In order to investigate the effect of rotation of the head and eyes upon performance with the Streaming Lights and also with the Flashing Lights on the Helmet, the subsidiary central display was used (see Fig. 2). The subject began each experimental period by fixating one of the two 'central' displays. This contained one or more illuminated spots, while the other 'central' display was blank. After a prearranged period, which could not be predicted by the subject, the illuminated spots were switched to the other 'central' display. The subject was required to fixate and respond to whichever 'central' display was illuminated. This alternation of displays required horizontal head and eye rotations through an arc of 70°. In each period the central task switched 10 times.

3.3. *Results*

In comparing the four displays, scores from only the last two days of the experiment were considered. The mean scores are shown in Table 2. Because

Table 2. Scores on the acquisition task and the effect of divided attention upon the central task

	Streaming Lights (without head rotation)	Barber's Poles (without head rotation)	Flashing Lights on the helmet (without head rotation)	I.L.S. Meter (without head rotation)	Streaming Lights (with head rotation)	Flashing Lights on the Helmet (with head rotation)
Number of subjects	6	11*	6	5	6	6
Time for acquisition (sec)						
In 2 dimensions: Mean	4·72	3·08	2·16	2·42	5·63	2·39
S.D.	0·96	0·87	0·57	0·59	0·89	0·16
In 1 dimension: Mean	3·14	2·18	1·36	1·80	4·10	1·55
S.D.	0·69	1·04	0·41	0·40	0·81	0·07
Trials with an acquisition time of 5 sec. or more.	22%	12%	0·9%	0·8%	35%	0·9%
Central task:						
Increase in reaction time (sec): Mean	0·16	0·091	0·12	0·15	0·14	0·13
S.D.	0·047	0·043	0·023	0·026	0·040	0·056
Missed signals: Mean	0·5%	0·7%	0·1%	0·4%	0·5%	0·3%
A.H.4 intelligence test:						
Mean	84	71	81	65	81	53
S.D.	16·0	17·6	10·6	17·7	15·2	13·0

*Of these 11 subjects, 6 had only the right-hand altitude pole, whereas 5 had both altitude poles. The differences between these two sub-groups were not significant (Mann-Whitney tests). Their scores have therefore been pooled.

only the four largest sizes of error were presented on the Barber's Poles, the other tabulated results also exclude trials with the smallest size of error.

Any trial upon which acquisition had not been completed within 10 sec was terminated and the time for acquisition was entered as 10 sec. The mean times for acquisition in two dimensions are based upon whichever of the two times for bearing or altitude was the longer in each trial. The percentage of trials upon which acquisition in either one or two dimensions took 5 sec or more is also shown. The one second for which the target had to be held before the dekatron timers stopped is not included in the times shown in Table 2.

(i) *Scores on the acquisition task.* The shortest mean times for acquisition were obtained with the Flashing Lights on the Helmet without head rotation. The next shortest were obtained with the I.L.S. Meter. The differences between these two pairs of means were not significant (Mann-Whitney test). The means with Barber's Poles were significantly longer than with Flashing Lights on the Helmet without head rotation ($P < 0{\cdot}05$), but the differences between Barber's Poles and the I.L.S. Meter were not significant. The means for the Streaming Lights condition without head rotation were significantly longer than for the Barber's Poles ($P < 0{\cdot}05$).

The small detrimental effect of rotation of the head and eyes was not significant. Although when rotation of the head was required with Flashing Lights on the Helmet the two lamps which indicated errors in azimuth were not placed symmetrically (see Fig. 7 (b)), the mean times for acquisition with left and right control movements were not significantly different (Wilcoxon test).

The only significant difference between mean times for acquisition in bearing and altitude occurred in the Streaming Lights condition without head rotation: times for acquisition in altitude were longer than for acquisition in bearing ($P < 0{\cdot}05$, Wilcoxon test).

(ii) *Central task.* The mean reaction time to the central task alone was 0·35 sec. This was increased by an average of about 40 per cent when a flight-director display had to be used simultaneously. The mean increase was not significantly different whether Barber's Poles were used, or the Flashing Lights on the Helmet without head rotation (Mann-Whitney test). Both these displays produced significantly smaller increases than either the I.L.S. Meter or the Streaming Lights without head rotation ($P < 0{\cdot}02$). The increases with these latter two displays were not significantly different. When rotation of the head was required, increases in reaction time to the central task were not significantly different from the increases produced by the same displays without rotation of the head. The type of flight-director display had no significant effect upon the mean percentage of missed signals on the central display.

(iii) *Individual differences.* The standard deviations of the 'time-off-target' scores shown in Table 2 indicate that individual differences were much smaller with Flashing Lights on the Helmet with head rotation than with any of the other displays.

The mean scores on A.H.4 for the groups were not significantly different (Mann-Whitney tests). Differences in intelligence between groups were correlated to some extent with the mean differences between groups in time for acquisition (tau=0·49, Kendall Rank Correlation Coefficient, see Siegel 1956, p. 213) and also with the mean differences in increase in reaction time to the central task (tau=0·35) but the correlations were not significant.

§ 4. Experiment III. Getting Back on to Course with Combined Flight-Director Displays

Flashing Lights attached to the subject's helmet were found in Experiment II to be excellent at drawing his attention to a sudden error in the flight of the 'aircraft' and also in indicating to him the direction of the control movement required to correct the error (see Table 2). However, rate of flash is not a very successful code for indicating the size of the required correction. In contrast, a crossed-pointer display gives an excellent indication of the direction and size of the error, but does not always attract attention at once. The combination of Flashing Lights on the Helmet and the I.L.S. Meter was therefore tested to determine whether this would lead to a more rapid correction of errors than either display alone. The combination of Streaming Lights and the I.L.S. Meter was also tested. The experiment was performed in three parts: (1) The I.L.S. Meter plus a simple warning light were compared with the same combination plus the Streaming Lights. (2) The I.L.S. Meter plus the warning light were compared with the I.L.S. Meter plus Flashing Lights on the Helmet. (3) The I.L.S. Meter plus both the Warning Light and the Streaming Lights were compared with Flashing Lights on the Helmet alone.

As the experiment was exploratory, subjects were each given two conditions to perform. The method was essentially that used in Experiment II: sudden errors were introduced into the flight-director system while the subject was performing the central task.

4.1. *Apparatus*

The warning light was a combination of two 6-watt filament lamps, lying side-by-side in a white translucent shield. One of these lamps was illuminated immediately a display indicated an error in bearing. The second lamp was illuminated immediately a display indicated an error in altitude. The relative positions of the two lamps could not be distinguished. Two lamps were used instead of one simply because this was easier to do electrically. The time they took to come on was about the same as that taken to initiate errors in the flight-director displays.

The central task was the same as that in Experiments I and II, but only the subsidiary 'central' display was used (see Fig. 2), and the warning light was placed immediately on the left of this display. The horizontal interval between the warning light and the main central display subtended an angle of 67° at the subject's eye. As in Experiment II the I.L.S. Meter was located 10° vertically below the main central display. The altitude displays of the Streaming Lights and the Flashing Lights on the Helmet were fixed as for the head-rotation conditions of Experiment II (see Figs. 2 and 7 (b)).

4.2. *Subjects and Procedure*

The subjects were 18 naval ratings between the ages of 17 and 30 years (median age 20). All had normal uncorrected vision and had not been tested in previous experiments with the simulator. They were divided into three equal groups, each assigned to one part of the experiment.

The procedure for parts (1) and (2) of the experiment was as follows: The subject always started by fixating the subsidiary 'central' display and

responded to changes in the pattern of spots. On the appearance of the warning light, or an indication from the flight-director system, he turned his head to fixate the I.L.S. Meter and corrected the error signal as quickly as possible. When the Streaming Lights or the Flashing Lights on the Helmet were used in addition to the I.L.S. Meter, both the displays presented the error signals in their respective ways at exactly the same time. Thus the subject could start his response as soon as the error was signalled by the Streaming Lights or the Flashing Lights on the Helmet, before he had fixated the I.L.S. Meter.

Until an error was indicated by the flight-director system, the subject responded to the central task only. As soon as he saw an error he concentrated his attention entirely upon the flight-director display(s). He was not required to respond to the ' central ' display during this period of concentrated attention, although the display continued to change. When the error had been corrected, the experimenter introduced the equal but opposite error and the subject re-centred the control column. He then turned his head back to the right, fixated the subsidiary ' central ' display and continued the central task until the next error was displayed.

On the 9 days of training and experiment which followed the introductory day, the subject used each of the two combined flight-director systems included in his part of the experiment. The order in which the combinations were practised was reversed on alternate days.

In part (3) of the experiment the subject practised with the I.L.S. Meter plus the Streaming Lights and warning light for the first 5 days. The Flashing Lights on the Helmet were demonstrated on the sixth day, so that it was alternated with the combined system on the last 4 days only and thus received much less practice. In the Flashing Lights on the Helmet condition the subject fixated the I.L.S. Meter immediately an error was displayed, although it was not shown on the Meter. In other respects the procedures of parts (1), (2) and (3) were similar.

4.3. *Results*

The results shown in Table 3 are from the last 2 days of the experiment only.

(i) *Scores on the acquisition task.* In Part (1), the mean times for acquisition with the I.L.S. Meter plus the warning light and Streaming Lights were not significantly different from the mean times with only the I.L.S. Meter plus the warning light (Wilcoxon test). In Part (2), the mean times with the I.L.S. Meter plus Flashing Lights on the Helmet were significantly shorter than mean times with only the I.L.S. Meter plus the warning light ($P < 0{\cdot}05$). In Part (3), for acquisition in two dimensions, Flashing Lights on the Helmet gave significantly shorter mean times than the I.L.S. Meter plus both the warning light and Streaming Lights ($P < 0{\cdot}05$), but for acquisition in only one dimension, the two conditions did not differ significantly.

(ii) *Central task.* The mean reaction time to the central task alone was 0·35 sec. The increase in reaction time did not vary significantly with different combinations of the flight-director displays (Wilcoxon tests). There were no missed signals in this experiment, since the ' central ' task did not have to be performed while correcting errors. However, reaction time to the central

task was increased by having to be *ready* to correct errors at any time. The subject had always to be on the look out for the appearance of an error signal on the flight-director display, because he could not predict when it would occur.

(iii) *A.H.4 scores.* There were no significant differences in the mean scores on A.H.4 between the three different groups of subjects (Mann-Whitney tests).

Table 3. Scores on the acquisition task when flight-director displays were used in combination

		Part (1)		Part (2)		(Part 3)	
		I.L.S. Meter plus Warning Light	I.L.S. Meter plus Warning Light plus Streaming Lights	I.L.S. Meter plus Warning Light	I.L.S. Meter plus Flashing Lights on the Helmet	I.L.S. Meter plus Warning Light plus Streaming Lights	Flashing Lights on the Helmet alone
Number of subjects		6		6		6	
Acquisition time (sec)							
In 2 dimensions:	Mean	2·52	2·54	2·14	1·39	1·98	1·78
	S.D.	0·14	0·22	0·24	0·27	0·41	0·10
In 1 dimension:	Mean	1·78	1·87	1·43	0·93	1·60	1·38
	S.D.	0·24	0·11	0·16	0·09	0·31	0·24
Trials with an acquisition time of 5 sec. or more		0·1%	0·1%	0·25%	0%	0·25%	0%
Central task: Increase in reaction time (sec):	Mean	0·10	0·12	0·13	0·13	0·17	0·15
	S.D.	0·038	0·047	0·053	0·054	0·075	0·064
A.H.4. intelligence test:	Mean	75		78		72	
	S.D.	8·8		16·0		13·5	

§ 5. Discussion

5.1. *Attention to the flight-director displays upset the central task*

In Experiment II the man sometimes had to react to the central task while using a flight-director display to bring the simulated aircraft back on to course. Part of the increased reaction time to the central task could therefore have been due to interference between simultaneous responses to the two tasks. This could not have been the case in Experiment III, however, for in this responses to the two displays never had to be made simultaneously. The rather similar increases in reaction time to the central task in the two experiments (compare Tables 2 and 3) suggest that interference between simultaneous *responses* was not a major factor in Experiment II. Most of the increase in reaction time to the central task in both experiments must, therefore, presumably have been due to the increased number of *choices* of response in the combined task: having to react to the central task *or* the flight-director display, whichever of the two next presented a signal. In other words, the need to attend to the additional channel of information, whether or not the information demanded action, upset the central task, in much the same way as in Experiment I in which the simulated aircraft had to be controlled continuously. Presumably

additional *monitoring* lowers the standard of monitoring other displays: the design engineer must look upon the pilot as a ' communication channel of very limited capacity ' (Broadbent, 1957).

The indication in Tables 1 and 2 that the Barber's Poles interfered least with the central task may be accounted for in two ways. Firstly, it is known from other experiments (Bahrick, Fitts and Rankin 1952) that instructions which emphasize the importance of good performance at one of two tasks performed simultaneously, can improve a man's performance at this task, but lowers performance at the other. During training the experimenter could have encouraged the men working with the Barber's Poles to pay rather more attention to them, until their reaction times to the central task had increased to the level found with the other displays. Performance with the Poles would then presumably have been somewhat better, though it would probably not have reached the level achieved with the Flashing Lights on the Helmet or the I.L.S. Meter.

Secondly, the signals from the Streaming Lights and the Flashing Lights on the Helmet resembled the signals of the central task, to the extent that all three displays involved lamps going on and off. In the early stages of practice, subjects sometimes confused the signals from the central and the flight-director displays and made inappropriate responses. This confusion disappeared with training, but the inhibition of inappropriate responses might have increased the reaction times to the central task. In contrast, the Barber's Poles simply moved without going on and off. The signals were thus quite different from those of the central task, and were never confused, even early in practice. This lack of confusion might account, at least partly, for the smaller increases in reaction time to the central task found with the Poles. If this is so, a different central task might have shown the same deterioration with the Poles as with the other flight-director displays. Signals from the I.L.S. Meter also were not confused with those from the central display, but the subject had to look directly at the meter in order to correct an error. The ' central ' task was thus not always fixated directly, and so would presumably be reacted to more slowly.

5.2. *Flashing Lights on the Helmet was the best display for monitoring*

Table 2 shows that Flashing Lights on the Helmet gave shorter times for acquisition than any other single display investigated. Observation of the subjects suggested two reasons for this. First there was the great *attention-getting* value of the display. Due to its proximity to the eye, each lamp stimulated a large area of the retina when illuminated. The Streaming Lights and Barber's Poles were less adequate in this respect. The start of a movement of an already illuminated display attracts the attention less immediately than the lighting up of a display.

The second advantage of the Flashing Lights display was its immediate *directional* indication. ' Right ' indicated a control movement to the right, and ' up ' indicated a backward control movement. In contrast, neither the Streaming Lights nor the Barber's Poles gave a really adequate directional indication. Direction of movement of a display appears to be less ' compatible ' with the position of a control than does the position of a display.

The weakness of the Flashing Light display, as also of the Streaming Lights and Barber's Poles, was in presenting information on the *size* of the control movement which was required. Subjects found it difficult to interpret rate of flash, or rate of movement, in terms of the size of the required control movement, especially with the faster rates. In contrast, the I.L.S. Meter presented information on the size of the required control movement in an easily assimilable form, once the man had learnt the ratio of control movement required for a given size of display movement. The major weakness of this display was in attracting the man's attention. Once an error of a fixed size had been registered, the display ceased to move. If the man did not happen to notice the brief movement, it might be an appreciable time before he realized that there was an error to correct.

The combination of Flashing Lights on the Helmet for attracting the man's attention and enabling him to start his control movement in the correct direction, with the I.L.S. Meter for making the control movement of exactly the correct size, gave the shortest times for acquisition found in any of the experiments: 1·39 sec for acquisition in two dimensions, and 0·93 sec for acquisition in one.

5.3. *Head rotation hardly affected performance with the peripheral displays*

A possible disadvantage of displays which use peripheral vision is that when the pilot is required to rotate his head or eyes about 90°, it may not be clear in which direction to move the control in response to a signal. This could apply particularly to displays such as the Flashing Lights on the Helmet, which rotate with the head; for when the head is turned, the directional signals and the corresponding control movements occur in non-parallel planes. Table 2 shows that this disadvantage made only a relatively small difference to the times required for acquisition. The increase with head rotation was less with Flashing Lights on the Helmet, which rotated with the head, than with Streaming Lights which did not and neither increase due to head rotation was significant. Such increase in acquisition time as there was could have been due, at least partly, to the additional difficulty of the 'central' task, which switched at unpredictable intervals from the main central display to the subsidiary display at the side and back again.

5.4. *Combined responses were made to displays in two dimensions*

A possible difficulty with Streaming Lights and Barber's Poles, and also with the Flashing Lights, was that errors in the two dimensions were presented separately. In order to make a single control movement of the correct extent and in the correct direction, the man had to combine the information from two separate displays. The results in Table 2 show that, after training, acquisition in two dimensions took only from 35 per cent to 60 per cent longer than acquisition in a single dimension. This suggests that the man did not respond to the two separate displays successively—if he had, acquisition in two dimensions would have taken almost twice as long as acquisition in a single dimension. Since time for acquisition in two dimensions was based upon whichever of the two times for bearing and altitude was the longer in each trial, acquisition in two dimensions would be expected simply on a chance basis to take longer than

acquisition in one dimension on two-thirds of the trials. This is about the proportion observed after training. It suggests that acquisition in two dimensions was carried out very largely as a single movement.

5.5. *Two altitude displays introduced conflicting control-display relationships*

A very real difficulty was found with the Barber's Poles when an altitude display was placed horizontally on both sides of the azimuth display. Although the two altitude Poles presented the same information, they could not be apprehended as a single display, presumably because they were separated by the azimuth Pole which presented independent information. The man thus worked with the azimuth Pole and only one of the altitude Poles, and directed his attention to the corner at which they met. Let us assume that he used the corner at the *left*-hand edge of the azimuth Pole. In order to combine the information from the two Poles which met here, he had to learn the following control-display relationships (see Figs. 3 and 6).

Perceived Display Movement	*Control Movement Required*
Two Poles converging	Forward and to left
,, ,, diverging	Backward and to right
,, ,, sweeping right	Forward and to right
,, ,, ,, left	Backward and to left

If the man switched his attention to the corner at the *right*-hand edge of the azimuth Pole, the correct control-display relationships were now:

Perceived Display Movement	*Control Movement Required*
Two Poles converging	Forward and to *right*
,, ,, diverging	Backward and to *left*
,, ,, sweeping right	*Backward* and to right
,, ,, ,, left	*Forward* and to left

These relationships are different from those at the other corner. (The differences are shown in italics.) Subjective reports indicated that after training the man stuck to one corner or the other; he did not switch his attention between them. This may explain why presenting the man with the two altitude Poles gave the same scores in both acquisition and continuous tracking as presenting the man with only one of them.

If Streaming Lights or Barber's Poles are to be used in aircraft, two altitude displays, one on each side of the azimuth display, appear to be essential. This is because when the head is turned in the opposite direction to a display fixed for viewing with the peripheral part of the eye, the display becomes invisible. The full display system will, however, thus have built into it two different sets of control-display relationships, depending upon which altitude pole can be seen. This is a very definite danger in a display system designed for an aircraft.

5.6. *Why controlling in altitude was sometimes harder than controlling in bearing*

Table 1 shows that continuous control of the simulated aircraft using Streaming Lights or Barber's Poles was more successful in bearing than in altitude. This is unlikely to have been due simply to the relative difficulty of the two cams generating the errors, or to the directional control-display

relationship, since with the I.L.S. Meter continuous control in altitude was the more successful. Result 3.3 (i) shows that the correction of sudden errors in the course of the 'aircraft' using Streaming Lights was more rapid in bearing than in altitude, when rotation of the head was not required. In this experiment, corrections using the Barber's Poles and using the Streaming Lights with rotation of head, showed no significant differences between the two dimensions of control.

At least three factors may have been responsible for this pattern of results. Firstly, except when rotation of the head was required, the Streaming Lights and Barber's Poles displaying altitude errors were further in the periphery of the field of view than the corresponding display of errors in bearing. This would tend to make the information displayed by them more difficult to see.

Secondly, in the case of the Barber's Poles, the poles which displayed errors in altitude were seen obliquely, since they were mounted horizontally fore and aft. With the same rate of display movement, and hence with the same required size of control movement, the altitude displays thus appeared to move more slowly than the azimuth display. In addition, when there were two altitude poles, displacement of the head to either side made one altitude pole appear to move more slowly than the other. This would tend to make errors displayed by the altitude poles the more difficult to correct.

Thirdly, in the case of the Streaming Lights, the row of neon lamps displaying errors in altitude was fixed vertically, in contrast to the horizontal row of lamps displaying errors in bearing. It may be easier to estimate direction and rate of movement in the horizontal dimension in peripheral vision, since we frequently see objects moving horizontally out of the corners of our eyes when travelling in moving vehicles, whereas we seldom see pure vertical movement unconnected with the apparent expansion of approaching objects. This explanation is supported by the finding that in both Experiments I and II the differences between performances on the two dimensions were considerably reduced by practice.

5.7. *The adequacy of laboratory comparisons*

The conditions in which flight-directors will be used are certain on occasions to be extremely stressful. The differentiating effects of task-induced stress upon systems which appear, after practice, to be almost equally efficient have been demonstrated experimentally (Garvey and Taylor 1959). In any comparison of flight-directors the 'pilot', as well as receiving adequate training in all systems in the comparison, should therefore be stressed as highly as possible, or differences between alternative displays may not be disclosed. In this respect the results of the present experiments are perhaps more useful than those obtained from flight trials in good weather.

This work was directed by Mr. D. E. Broadbent. Dr. E. C. Poulton helped with the reporting. Statistical advice was provided by Dr. M. Stone. Thanks are also due to the Blind Landing Experimental Unit of the Royal Aircraft Establishment for the loan of the I.L.S. Meter, and to the Instrument and Air Photography Dept., Farnborough, for the loan of the Barber's Poles. The

majority of the tests were carried out by S. D. Holmqvist. The remainder were carried out by M. C. Woodhouse and I. D. Brown, who also analysed the results and prepared the report. Subjects were provided by the Royal Navy. Financial assistance was received from the Medical Research Council and the Air Ministry Flying Personnel Research Committee.

Les dispositifs de pilotage suivants ont été comparés au laboratoire sur un simulateur de vol ordinaire et dans des conditions contrôlées de bruit et d'éclairage.

(*a*) *Les lumières mobiles:* indiquent l'erreur de pilotage d'un " avion " par le sens et la vélocité du mouvement apparent des lumières mobiles.

(*b*) *Les barres de Barber:* indiquent l'erreur par le sens et la vitesse du mouvement de translation apparent d'une raie hélicoïdale blanche peinte sur un tube noir.

(*c*) *Les lumières flashantes:* celles-ci, fixées au simulateur ou bien au casque que porte le sujet, indiquent l'erreur commise dans chaque dimension par la position et la rapidité des allumages d'une lampe à éclats.

(*d*) L'I.L.S.-mètre (I.L.S. = atterrissage aux instruments): se présente sous la forme d'un " instrument de zéro " et indique les erreurs par la position de deux aiguilles se coupant à angles droits.

Tous ces dispositifs ont été conçus pour transmettre l'information de pilotage à un pilote qui surveille l'environnement extérieur et tous, sauf le dernier, transmettent l'information en vision périphérique.

En situation de pistage continu, le temps hors-piste avec les lumières flashantes ou l'I.L.S.-mètre représente le quart du temps hors-piste avec les lumières mobiles ou les barres de Barber. La correction d'erreurs apparaissant subitement était plus aisée dans le cas des lumières flashantes fixées au casque qu'avec l'un quelconque des autres dispositifs étudiés. Ceci peut être imputé au fait que ce procédé attire particulièrement l'attention et fournit une indication immédiate de la direction par la position des signaux. Le point faible du système des lumières flashantes sur casque réside dans une insuffisante indication de la grandeur des erreurs. Il en est de même des barres de Barber et des lumières mobiles. Seul l'I.L.S.-mètre s'avère efficace à cet égard, bien qu'il n'attire pas toujours l'attention du sujet dès qu'une erreur se produit. En associant les lumières flashantes sur casque à l'I.L.S.-mètre, on obtient le maximum d'efficacité dans la correction des erreurs.

Utilisant une tâche centrale comme critère d'efficience, ona constaté que la surveillance de l'un quelconque des dispositifs de pilotage entraîne un allongement de 40 pour cent des temps de réaction aux signaux de cette tâche centrale. Cet allongement s'observe aussi bien lors de l'exécution du contrôle simulé que lors de sa non-exécution. Ce fait suggère que c'est l'obligation d'être attentif à un canal d'information supplémentaire qui interfère avec la tâche centrale et non l'obligation simultanée d'agir.

Les mouvements latéraux de la tête modifient l'angle sous lequel le sujet voit les barres de Barber disposées bout-à-bout horizontalement et donnant des indications sur l'altitude. De ce fait le mouvement apparent du dispositif se trouve modifié, ainsi que la proportion des présentations entraînant des mouvements de correction. Il s'ensuit, de la part du sujet, des omissions dans les corrections à effectuer ou des mouvements de correction anormaux. En plus, dans l'utilisation des barres de Barber, les relations directionnelles dispositif-commande sont modifiées lorsque l'attention est attirée d'un côté de l'indicateur d'azimuth vers l'autre. Ceci peut se produire lorsque, dans un avion, le pilote tourne la tête et les yeux et peut ainsi constituer un danger.

Folgende Flugleitsignale wurden im Laboratorium an einem einfachen Flugzeug-Simulator bei kontrollierter Lärm- und Be-leuchtungsstärke verglichen:

(*a*) " Strömende Lichter ", die einen fehlerhaften Flug nach Richtung und Geschwindigkeit der scheinbaren Bewegung der " strömenden Lichter " vorgaben;

(*b*) " Barbier-Säulen ", die Fehler der Richtung und Geschwindigkeit der Translations-Bewegung einer Schraubenlinie auf einer schwarzen, sich drehenden Säule vorgaben;

(*c*) Blitzlichter, die am Simulator oder am Helm der Versuchsperson angebracht waren, um Fehler in jeder Dimension durch die Stellung und Blitzfrequenz eines einzelnen Blitzlichtes vorzugeben;

(*d*) "I.L.S.-Meter" (Messgerät für Blindlandung), der eine Null-Einstellung zweier rechtwinklig zueinander sich bewegenden Anzeigelinien verlangte.

Alle diese Leitsignale sollten dem Piloten Navigations-Informationen bieten, während er die Aussenwelt absuchte. Alle Signale, bis auf das letzte, boten die Information im peripheren Gesichtsfeld.

Bei fortgesetztem " Spuren " eines Ziels war die Zeit des Abweichens von der Spur durch Blitzlichter oder den " I.L.S.-Meter " etwa ein Viertel so lang wie durch " strömende Lichter " oder " Barbiersäulen ". Wurden plötzlich Fehler durch Blitzlichter am Helm dargeboten, so wurden sie rascher korrigiert als bei irgend einer anderen der untersuchten Darbietungen. Das war vermutlich die Folge der hohen Aufmerksamkeits-Attraktion und der unmittelbaren Richtungsanzeige dieses Signals. Die Schwäche der Blitzlichter am Helm, wie auch der " strömenden Lichter " und " Barbiersäulen ", lag in der schlechten Anzeige der Fehlergrösse. In dieser Hinsicht war der " I.L.S.-Meter " am besten, wenn er auch nicht immer die Aufmerksamkeit des Mannes so rasch auf sich zog wie der Fehler angezeigt wurde. Die Kombination von Blitzlichtern am Helm und " I.L.S.-Meter " führte zu den schnellsten Korrekturen bei diesen Experimenten.

Die Reaktionszeit auf zentral dargebotene Signale hin erhöhte sich um etwa 40 Prozent wenn die Aufmerksamkeit durch irgend eines der Flugleitsignale in Anspruch genommen war. Diese Erhöhung war etwa gleich gross, wenn eine simulierte Kontrolle des Flugzeugs erfolgte oder nicht. Das lässt vermuten, dass die Ablenkung der Aufmerksamkeit durch den zusätzlichen Kanal, nicht aber die Forderung simultaner Tätigkeit, die zentrale Tätigkeit störten.

Die Leistung bei Blitzlichtern am Helm und " strömenden Lichtern " zeigte nur eine geringe, nicht signifikante Störung bei gelegentlicher Drehung von Kopf und Augen um 70°.

Seitwärtsbewegungen des Kopfes änderten den Winkel, den senkrecht montierte " Barbier-Säulen " den Augen übermittelten, und damit die Höhen-Information. Das änderte die scheinbare Bewegungsgeschwindigkeit des Signals und das scheinbare Verhältnis Signal/Kontrolle. Die Versuchsperson konnte so kleine Fehler übersehen oder falsch korrigieren. Zusätzlich wechselte das Richtungsverhältnis Signal/Kontrolle, wenn die Aufmerksamkeit von einem Ende der Azimute zum anderen wanderte. Das könnte einem Flugzeug gefährlich werden, wenn der Pilot Kopf und Augen drehte.

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THE INFLUENCE OF NOISE ON TWO DISCRIMINATION TASKS

By A. F. Sanders

Institute for Perception, RVO–TNO, Soesterberg, The Netherlands

Recent research has revealed that noise effects on work become apparent in an increasingly irregularity of reaction times instead of in a general decrease in the total number of reactions. This paper is concerned with the measurement of the degree of irregularity in two paper-and-pencil tasks. Both tests were performed twice on different days for half an hour each. The experiment was designed to compare two different noise conditions : in one the noise changed randomly about an average level of 75 dB., in the other it was steady at 70 dB.

The number of reactions in every minute was scored. To reach conclusions from the scores about the degree of regularity of the reaction times, a measure of the variance of the scores was used. Since there appeared a linear trend of score with time, it was decided to calculate the variance of the differences of score between successive minutes rather than of the scores themselves. Two variances were calculated for each day's work at each task, one over the first fourteen, and one over the last fourteen differences. The ratio of the variances (variance quotient) was taken as an indication of the change of irregularity as performance proceeded. The results showed that in one task the variance quotient was singificantly larger under conditions of varying than steady noise. In the other task the same trend appeared in the second day's session but not in the first. The results favour Broadbent's hypothesis that unpredictable noise affects performance more than does monotonous noise.

§ 1. Introduction

A considerable number of studies, devoted to the effects of noise on work have given various but mostly inconclusive results (Kryter 1950). More recent research (Broadbent 1954) has shown several shortcomings in the older investigations. One of the criticisms is concerned with the question how a noise effect can become apparent in performance. The earlier experimenters looked in vain for differences between noise and quiet conditions in terms of the total number of reactions, expecting a lower total or, sometimes, a decrease in time, when the subjects were exposed to noise. Broadbent showed that it is more promising to consider the *regularity* of the performance times. In some tasks he found an increasing irregularity when the task was performed under noisy conditions : from time to time the work was interrupted by short pauses (mental ' blinks ' or ' blocks '), which increased in frequency as the task progressed. The total number of reactions in a given workperiod was not altered however, since the blocks were compensated for by spurts which made up the lost time. In some tasks it has also been found that instead of blocks there is an increase in the number of wrong responses. This has been explained as an indication that the blocking occurs primarily in the perceptual mechanism and not in the motor system.

Measurement of the effect of noise is easy when it leads to an increased number of mistakes, but when blocks appear measurement is more complicated. Up till now it has been done mainly by recording performance times which are substantially longer than average or, perhaps better, by measuring the variability of performance times. For example Fraser (1953), in a study of vigilance, found an increase in the variance of reaction times as the task proceeded. In paper-and-pencil tasks however we cannot deal with separate

performance times for every item, but we can record the numbers of reactions in given periods and calculate the variance of the distribution of these numbers. If this method is adequate as an indication of the effects of noise, we should expect a larger variance near the end of the workperiod than at the beginning under noisy conditions, but little or no effect under quiet conditions. Alternatively, of course, there might be an increase in the number of mistakes under noisy conditions but no increase, or a smaller increase, under quiet conditions. Broadbent (1953, 1958) suggested that performance might be more affected by varying than by continuous noise since the former would have more attention-getting value (cf. Berlyne 1951). The main purpose of this paper is to test this hypothesis.

§ 2. Method and Procedure

The tasks were variations of two psychological tests frequently used in Holland: the Bourdon–Wiersma cancelling test and the Kraepelin addition test. The former consists of rows of dot configurations, each row containing twenty-five items—eight items of four dots, eight of five and nine of three. The subjects were instructed to cancel each item in a prescribed way (three dots with a horizontal stroke, four dots with a vertical one, and five dots with a circle). Every minute the subjects were given a signal to mark off their performance in that minute. The test lasted half an hour.

The Kraepelin test was modified to a discrimination task like the Bourdon–Wiersma. The test form consists of rows of digits from zero to nine. The instruction was again to cancel in a prescribed way (the digits 0, 2 4, with a horizontal stroke, 1, 3, 5 with a vertical stroke, 6 and 8 with an oblique stroke and 7 and 9 with a circle). Again the subjects were given every minute a signal to mark off their performance. The length of the test was again half an hour.

A comparison between the Bourdon–Wiersma and Kraepelin tests suggests that the latter is more difficult in that the inclusion of several digits in each class of reaction and four possible types of cancellation instead of three, means a more complicated decision for each reaction. A difference in the level of difficulty of the two tests may be important because of the finding by Broadbent (1954) of a difference between more and less difficult tasks in relation to the effects of noise.

Two conditions were compared: one with changing and one with steady white noise presented by headphones. The former consisted of sixteen tones (ranging from 85–1360 Hertz in equal steps of 85 Hertz, all being equal in loudness), which were randomly varied with respect to duration and number sounded simultaneously: the average intensity amounted 75 dB. above a level of $2 \cdot 10^{-4}$ dynes/cm^2 with extremes at 90 and 65 dB. The distribution of intensities was random and approximately normal. The steady noise was of 70 dB intensity: generally no effects are found with white noise of this intensity. It was used instead of a quiet background to preclude suggestion effects.

Forty air force ratings served as subjects. They were all available for a fortnight period. In the first week they performed the Kraepelin test twice on different days. In the second week they performed the Bourdon–Wiersma test, again twice on different days. The subjects were randomly divided into four groups. One group (N–N) had varying noise on both days, another (S–S)

had steady noise on both days, a third (N–S) had varying noise on the first day and steady on the second, and the fourth (S–N) had steady noise on the first day and varying on the second. A short period of training was given before the first day's test. Subjects were instructed to work fast but without making mistakes.

§ 3. Results

The mean numbers of errors made (Table 1) did not rise from the first to the second half of each day's session, and although there was some tendency for more errors to be made under conditions of varying noise on the first day, errors formed a negligible percentage of the total numbers of reactions shown in Table 2. As is expected from previous research there appear to be no *overall* differences in achievement between varying and steady noise conditions, and the substantial rises between the beginning of the first day's session and the end of the second day's are found equally with varying and steady noise. The general level of performance is rather lower in the Kraepelin test than in the Bourdon–Wiersma, confirming that the Kraepelin test is the more difficult.

The separate scores for each minute of the test showed a linear increasing trend in time. As it is known that mean and variance are frequently correlated, it was decided to use the first differences of the scores instead of the scores themselves when computing variances. By ' first differences ' is meant the difference between the scores for every two successive minutes. Thus if we have 30–33–32–36–39 reactions as scores for successive minutes, the first differences are +3, −1, +4, +3. Two variances were computed for each subject, one for the first fourteen, and one of the last fourteen first differences of each day's session (the difference between the fifteenth and sixteenth minute was neglected).

Table 1. Mean numbers of errors during each half of each day's performance

	First day			Second day		
Group	*Noise*	*First half*	*Second half*	*Noise*	*First half*	*Second half*
Kraepelin test						
S–S	Steady	4·1	3·2	Steady	5·4	5·4
S–N	Steady	4·8	3·1	Varying	3·3	6·3
N–S	Varying	1·8	2·9	Steady	4·6	4·7
N–N	Varying	3·8	4·7	Varying	5·6	5·9
Bourdon–Wiersma test						
S–S	Steady	7·5	7·5	Steady	3·9	6·0
S–N	Steady	8·5	7·8	Varying	4·3	6·3
N–S	Varying	11·9	13·9	Steady	8·4	7·9
N–N	Varying	9·0	10·3	Varying	8·3	7·1

None of the differences between the first and second halves of a day's session was significant.

The variances thus computed are shown in Table 3. Those for the first half of each day's session show little consistent effect of varying as opposed to steady noise. Those for the second half, however, clearly tend to be higher under conditions of varying than under steady noise. This is clearly so for the Kraepelin task on both days, but for the Bourdon–Wiersma task it is marked on the second day only suggesting, perhaps, that with this task the effects of varying noise upon performance do not become marked until a good deal of practice has occurred.

Table 2. Mean numbers of reactions

Group	Noise	First day: First Half	First day: Second Half	Second day: Noise	Second day: First Half	Second day: Second Half
Kraepelin test						
S–S	Steady	585	723***	Steady	874	909
S–N	Steady	613	750***	Varying	858	903*
N–S	Varying	519	670***	Steady	826	871*
N–N	Varying	601	720***	Varying	838	826
Bourdon–Wiersma test						
S–S	Steady	826	945***	Steady	1194	1240
S–N	Steady	777	843**	Varying	964	1027*
N–S	Varying	781	838**	Steady	1005	1060*
N–N	Varying	805	877*	Varying	1089	1102

Significant differences *=P<0·05, **=P<0·02, ***=P<0·01 (t-test).

Table 3. Variances of first differences between scores of successive minutes of performance

Group	Noise	First day: First half	First day: Second half	Second day: Noise	Second day: First half	Second day: Second half
Kraepelin test						
S–S	Steady	46·0	49·2	Steady	49·2	44·5
S–N	Steady	63·3	58·0	Varying	42·6	99·9***
N–S	Varying	40·8	76·7*	Steady	60·4	53·9
N–N	Varying	37·8	74·5***	Varying	53·6	111·8**
Bourdon–Wiersma test						
S–S	Steady	45·5	45·8	Steady	63·8	59·5
S–N	Steady	60·6	72·6	Varying	45·8	83·5**
N–S	Varying	59·3	72·5	Steady	47·8	50·5
N–N	Varying	56·2	76·8	Varying	71·5	115·1*

Significant differences : *=P<0·05, **=P<0·02, ***=P<0·01 (t-test).

Table 4. Mean variance quotients

Group	First day: Noise	First day: Mean	Second day: Noise	Second day: Mean
Kraepelin test				
S–S	Steady	1·43	Steady	1·25
S–N	Steady	1·30	Varying	2·70
N–S	Varying	2·70	Steady	1·00
N–N	Varying	2·75	Varying	2·42
Bourdon–Wiersma test				
S–S	Steady	1·42	Steady	1·07
S–N	Steady	1·40	Varying	2·98
N–S	Varying	2·00	Steady	1·28
N–N	Varying	1·34	Varying	1·64

t-tests of the results of the Kraepelin tests showed the differences between days for groups S–N and N–S to be significant at the 5% level. An analysis of variance showed the difference between groups S–S and N–N to be significant at the 5% level.

t-tests of the results of the Bourdon–Wiersma test showed the differences between days to be significant for group S–N but not for group N–S at the 5% level. An analysis of variance showed, for groups S–S and N–N an interaction between groups and days significant at the 5% level.

The results shown in Table 3 indicate that the effects of varying as opposed to steady noise appeared in both tasks only after the subjects had been working for some time. In order to show this effect more clearly ratios were computed between the variances of the first and second halves of each day's session for each subject separately. Ratios were taken rather than differences because they place less emphasis on absolute values and because their distribution is more nearly normal.

The mean *variance quotients* thus computed are shown for both the two day's sessions together, in Table 4, from which it can be seen that the quotients were very clearly higher under conditions of varying than under steady noise in the Kraepelin test, and tended to be so in the Bourdon–Wiersma.

§ 4. Discussion

It is clear from the results that the variability in performance between one minute periods increased during the second half of the test session, when working under varying as opposed to steady noise. It appears that subjects can endure the varying noise for a time but that after a time its effects begin to show. A similar result was obtained by Broadbent (1954) and it suggests a principle which, if found to be general, would be important in considering the effects of environmental stress.

It is not clear why the effect should be more marked with the Kraepelin than with the Bourdon–Wiersma test. The lack of effect in the latter might be due to something in the nature of the task—*what* this may be is obscure—which made it resistant to the effects of varying noise at first, or which produced a variability of performance during early stages of practice which masked the noise effect.

Comparing the results with Broadbent's (1953), the question arises why in his task the subject showed an increasing number of errors instead of a larger variability, while in the present results the number of errors proved to be negligible. Two reasons for this discrepancy may be suggested :

(i) In this experiment, subjects were instructed to work fast *without making mistakes*. The stress on accuracy may have prevented a rise of errors.

(ii) The tests gave the subjects a great deal of receptor anticipation, since an ample preview of the coming stimuli was possible. From Poulton's work (1952) it may be inferred that preview reduces errors. In Broadbent's task preview was absent.

Sensitivity of the Variance quotient

In the present results the variance quotient averages 1·0, indicating a constant variability, when the tests are performed in steady noise despite the fact that blocking has been found to increase even in quiet conditions. It might therefore be argued that the variance quotient, as an index of increased irregularity of performance, is less sensitive than the measurement of the number of blocks, and that compensating spurts have balanced the blocks within one-minute periods when working in steady but not in varying noise. If this is true it would be worth while to compare the length and distribution of blocks in time, under conditions of steady and varying noise. It is possible that, as performance proceeds, the blocks under conditions of varying noise become longer or perhaps occur in larger groups than they do in steady noise.

Whatever the explanation, it is interesting to note that so far as the present results go, the varying noise showed an effect on performance at the average level of 75 dB compared with steady noise at 70 dB. This finding is in line with Broadbent's suggestion that changing noise is more harmful to performance than continuous. It may be further noted that the present results suggest that varying noise has effects similar to very intense, high-pitched steady noise.

The author is much indebted to Dr. J. P. van de Geer for valuable discussion and criticism of this paper and to Mr. J. Boogard for help with testing subjects.

La recherche récente a montré que les effets du bruit sur le travail se traduisent par une irrégularité croissante des temps de réaction au lieu d'une diminution générale dans le nombre total des réponses. Cet article envisage la mesure de ce degré d'irrégularité dans deux tests papier-crayon. Les deux tests furent appliqués à deux reprises, deux jours différents, à raison d'une demi-heure pour chaque test. L'expérience avait pour but de comparer deux conditions de bruit différentes : dans l'une le bruit variait au hasard autour d'un niveau moyen de 75 décibels et dans l'autre le bruit restait constant à 70 décibels. On a compté le nombre de réponses par minute. Pour tirer une conclusion concernant le degré de régularité des temps de réaction, on a utilisé la variance des scores. Comme une relation linéaire apparaissait entre les scores et le temps, on décida de calculer la variance des différences de scores entre minutes successives, plutôt que celle des scores eux-mêmes. Deux variances furent calculées pour la performance de chaque jour à chaque test : l'une couvrant les quatorze premières différences, l'autre couvrant les quatorze dernières. On a pris le rapport des variances (quotient de variance) comme indice de variation de l'irrégularité, à mesure que se déroulait l'épreuve.

Les résultats ont montré que pour l'une des tâches, le quotient des variances était significativement plus élevé dans le cas du bruit variable que dans le cas du bruit constant. Pour l'autre tâche, la même tendance est apparue au cours de la réplication du second jour, mais non celle du premier jour. Ces résultats favorisent l'hypothèse de Broadbent, selon laquelle un bruit imprévisible affecte la performance plus que ne le ferait un bruit monotone.

Neuere Untersuchungen haben gezeigt, dass Lärmwirkungen auf die Arbeit sich in einer zunehmenden Unregelmässigkeit von Reaktionszeiten statt in einer allgemeinen Abnahme der Gesamtzahl der Reaktionen auswirken. Diese Veröffentlichung befasst sich mit der Messung des Unregelmässigkeitsgrades bei 2 " Papier- und -Bleistift-Aufgaben ". Beide Tests wurden zweimal an verschiedenen Tagen, jedesmal 1/2 Stunde, ausgeführt. Das Experiment war angelegt, um 2 verschiedene Lärmbedingungen zu vergleichen : bei der einen wechselte der Lärm wahllos um einen Mittelwert von 75 dB, bei der anderen war er konstant 70 dB.

Die Zahl der Reaktionen in jeder Minute wurde gezählt. Um aus den Zahlen auf die Regelmässigkeit der Reaktionszeiten zu schliessen, wurde ein Mass der Varianz der Zahlen benutzt. Da sich ein linearer Trend der Zahlen mit der Zeit ergab, wurde die Varianz aus der Differenz der Zahlen zweier aufeinanderfolgender Minuten, und nicht aus den Zahlen selbst gebildet. 2 Varianzen wurden für jeden Tag und jede Aufgabe berechnet, eine über die ersten 14, die andere über die letzten 14 Differenzen. Das Verhältnis beider Varianzen (Varianzen-Quotient) wurde als Mass des Fortschreitens der Unregelmässigkeit im Verlauf der Arbeit benutzt. Die Ergebnisse zeigen, dass in der einen Aufgabe der Varianzen-Quotient bei wechselndem Lärm signifikant grösser war als bei konstantem Lärm. In der anderen Aufgabe zeigte sich der gleiche Trend am zweiten Tag der Aufgabe, doch nicht am ersten Tag. Die Resultate unterstützen Broadbents Hypothese, dass unvorhergesehener Lärm Leistungen stärker beeinflusst als monotoner Lärm.

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COMPARISON OF PACED, UNPACED, IRREGULAR AND CONTINUOUS DISPLAY IN WATCHKEEPING

By R. T. Wilkinson

Medical Research Council, Applied Psychology Research Unit, Cambridge, England

Many vigilance tasks require the detection of a critical feature or 'signal' appearing occasionally in a long series of displays presented automatically and at regular time intervals to the observer. The question is whether this work would be carried out more efficiently if the displays were presented (*a*) automatically but at *irregular* time intervals, (*b*) not automatically but when called for by the observer, or (*c*) if the discrete displays were abandoned in favour of a continuous display forming a background of 'noise' upon which the occasional critical feature were superimposed. These three alternatives have been compared with the first-mentioned standard form using the same basic vigilance test throughout. None of the alternatives was found to offer any advantages over the standard; the total numbers of signals seen was roughly the same and the level of signal detection still declined significantly during the watch whichever alternative was used.

Comparison of alternatives (*a*), (*b*) and (*c*) respectively with the standard prompt the following suggestions : firstly, that predictability of the test may be unimportant in deciding the degree of vigilance decrement. Secondly when the observer calls for the displays in his own time he may continue to do this automatically during his attentional lapses, thus he may be just as likely to miss signals as when the displays are presented automatically by a machine. The generality is questioned of the suggestion that fatigue will cause mainly failures of speed in unpaced work and accuracy in paced. Thirdly, a regularly repeating feature of the display may not necessarily be soporific or prejudicial to maintained vigilance.

Individual measures of intelligence, neuroticism and extroversion were unrelated to scores of signals seen and decrement in performance during the test. For the second of these scores this result means little because of the very low test-retest reliability of individual indices of vigilance decrement, in itself an interesting, though disturbing finding.

§ 1. Introduction

Watchkeeping and inspection often require an operator to examine a long series of displays for the occasional appearance of a critical trace on one of them, and it is a familiar problem that the ability to detect these 'signals' may decline with time spent continuously on the task. Because the displays are almost always generated mechanically or electrically it is usual for them to be presented automatically to the observer and at regular time intervals.

The question arises whether the decline in signal detection might be reduced by changing this mode of presentation. Three alternatives have been examined here and compared with the automatic, regular presentation. The first alternative was that, although the displays should still be presented automatically, the regularity of their appearance should be broken up by allowing them to appear at randomly varying intervals. The second was that the successive displays should no longer be presented automatically but that the observer should cause them to appear in his own time by pressing a key ; in other words the presentation was unpaced instead of paced. The third alternative was rather different from the rest ; it corresponded to some situations in which there is continuous rather than discrete presentation of the display. For example a naval lookout scanning the seascape is essentially searching a continuous display for the occasional slight change which denotes the presence of some important object ; a parallel in industry is the search for flaws in a continuous sheet of glass or film.

Examples of at least three of these forms of presentation in the laboratory as well as in the field have been reported by previous writers but it is difficult to compare them because they are embodied in tasks which differ in other respects. This study has attempted to make the comparison using the same basic test of vigilance throughout, the only changes being those necessary to produce the four different forms of display to be compared.

§ 2. Method

The Standard Vigilance Test, which was used for this study, has been described in a previous communication (Wilkinson 1960). The subject sits alone in a cubicle watching a screen 12 in. in dia. on the wall opposite for an occasional faint spot of light ; this appears for $\frac{1}{2}$ sec in any of eight possible positions on the screen, and is reported by pressing a key. The test lasts for one hour and a loudspeaker provides a continuous background of white noise at about 75 dB throughout. The subject is under observation during the test and he is informed of this. He is given no knowledge of how well or badly he is doing either during or after his performance.

In the present experiment there were four conditions, each of which involved a version of this test which corresponded to one of the four forms of presentation mentioned above :

(*a*) Paced Regular Condition. Throughout the test the subject heard a short buzz at $4\frac{1}{2}$ sec intervals ; he was told that the signal when it came could only occur immediately after one of these buzzes. In fact, there were 800 buzzes during the test and only 36 of these, irregularly spaced in time, were followed by the appearance of the signal on the screen.

(*b*) Paced Irregular Condition. This condition was identical with the previous one except that the buzzes, with or without a signal following them, were presented automatically at intervals varying randomly between 2 and 8 sec.

(*c*) Unpaced Condition. Here the subject himself caused the buzz to occur (with or without its attendant signal) by pressing a second key. Some restrictions had to be imposed to ensure that he maintained an average display interval of $4\frac{1}{2}$ sec so that he ended his hour's watch having seen no more and no less than the 800 displays which appeared in the two paced conditions. If he consistently pressed for a display too often a warning light came on and for a time he would find that he could obtain no more displays until the $4\frac{1}{2}$ sec average had been restored. If he continually pressed for displays too slowly another warning light came on and the display would be presented automatically at a 2 sec rate until once again the $4\frac{1}{2}$ sec average had been restored. Subject to these constraints the subject was completely free to decide when the display would appear for his inspection.

(*d*) Continuous Display Condition. In this condition the buzzes were removed. The subject now had no indication as to when the signal might occur, though the programme was the same as in the other conditions. He was thus scanning an unvarying background (the blank screen) for the occasional appearance of signals.

Seventy-two naval ratings between the ages of 18 and 30 were divided at random into four equal groups and assigned to the four conditions. On the Monday of the week in which they were tested they were given instructions and

a 5 min practice run in which 10 signals were given. On the Tuesday they carried out the first of two main tests, and on Thursday the second, at the same time of day and, of course, in the same condition.

§ 3. Results

3.1 *Mode of Display*

While there were differences in individual scores from the first to the second of the two main tests (to which we shall return later) the overall pattern of performance in the four conditions was substantially the same in both tests. Accordingly, when comparing conditions, the average of the two tests has been taken as the measure of performance.

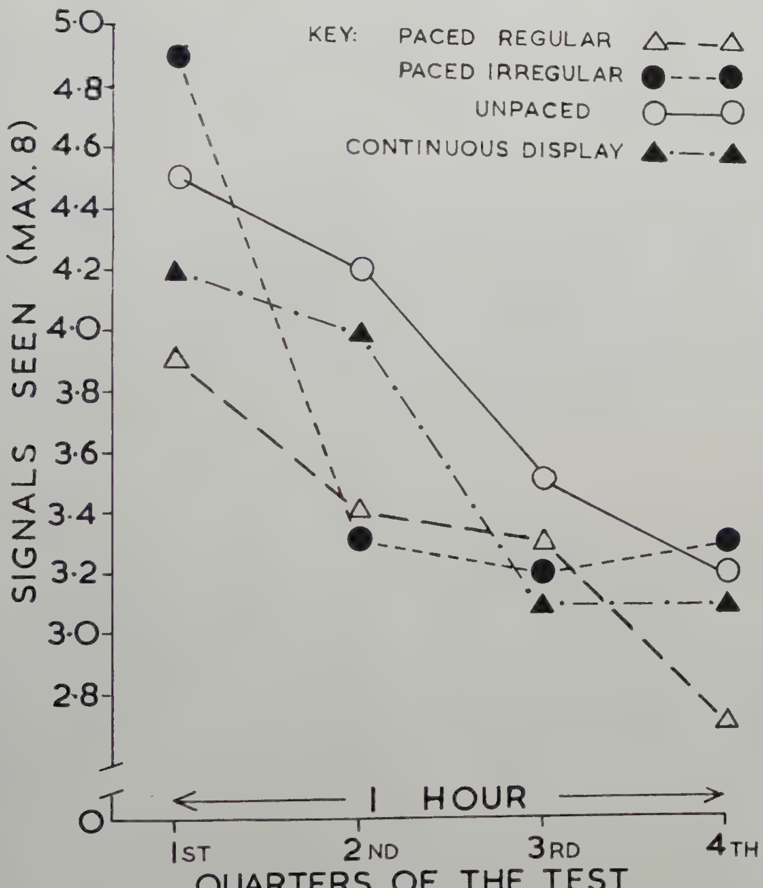

Figure 1. Comparison of performances with four different types of display.

Considering first the total number of signals seen, we find the Unpaced Condition yielded the best performance followed by Paced Irregular, Continuous Display and, finally, Paced Regular (Table 1). The differences between these conditions, however, were not large, especially when measured against the very wide individual differences of performance : the 5 per cent

confidence limits of the means all overlapped and therefore none of the means can be said to have differed significantly from any of the others.

It will be seen from Table 1, and in more detail in Fig. 1, that there was a decline in the efficiency of signal detection during the test in all four conditions ; this was significant beyond the 5 per cent level in each case. The greatest decline occurred in the Unpaced condition, followed closely by the Continuous Display condition. The Paced Irregular and Paced Regular conditions followed in that order. Examination of the confidence limits again shows that none of the differences between these means approach significance at the 5 per cent level.

Table 1. Signals seen during the whole test and decrement in performance during the test. Confidence limits are for P=0·05 (*t* test)

	Continuous Display	Paced Regular	Paced Irregular	Unpaced
Mean numbers of signals seen during the whole of the test (Max=32)	14·4±3·7	13·3±3·8	14·8±3·9	15·6±4·1
Mean decrement in performance between the first and second halves of the test	2·02±1·49	1·30±1·16	1·61±1·24	2·06±1·41

To summarize the position so far, there were some differences among the four conditions in overall performance level and in the tendency for performance to deteriorate during the course of the test ; in particular, the Unpaced condition was the best on the first of these counts and the worst on the second. Individual differences in performance among the subjects were so wide, however, that these results did not approach significance. So far as any conclusion can be drawn it must be that performance differed little between any of the four conditions.

3.2 *Individual Differences*

Considering now the individual differences themselves we may examine whether they were consistent from the first to the second main test by correlating the rankings of individual scores in the two tests for each condition separately. For scores of signals seen these correlations (Kendall's τ) were reasonably high ranging from $+0{\cdot}37$ to $+0{\cdot}56$ with levels of significance between P=0·016 and P=0·0007. Surprisingly, however, the same did not hold for the decrements of performance between the first and second halves of each test. The correlations for these were sometimes positive, sometimes negative and invariably insignificant. The results suggest that there are stable differences between individuals in their ability to *see signals* but that ability to *maintain signal detection* throughout a test is more changeable, likely to vary within an individual from time to time, perhaps as a function of practice or of other influences outside the control of the experimenter.

All subjects were given Heim's A.H.4 Test of Intelligence (1955) and also the Heron Questionnaire (1956) which is a possible measure of, on the one hand neuroticism, and on the other a dimension of extroversion or sociability. The scores of none of these showed any substantial correlation with scores for signals seen. Nor did they correlate with decrement score, but this means little in light of the low test-retest reliability of individual differences in this latter aspect of performance.

3.3. *Hour of the Day*

Finally, as individuals were always tested at the same time of day, at either 0900, 1000, 1100, 1330, 1430 or 1530 hours, it was possible to assess the level of efficiency at these different times. This gives, possibly, a more reliable indication of the effect of diurnal rhythm upon efficiency than would be obtained from subjects working on a test throughout the day, when the cumulative effects of fatigue might confuse the picture. Different levels of performance did occur (Table 2) but again the wide individual differences reduced their significance below acceptable levels. The most nearly significant result (which just failed to reach the 5 per cent level of probability) was that the deterioration in performance during the test was less in the afternoon than in the morning. No markedly different patterns of diurnal proficiency were found as between extraverts and introverts.

Table 2. Performance at different hours of the day averaged over all conditions

	Hour of the test					
	09.00	10.00	11.00	13.30	14.30	15.30
Mean number of signals seen during the whole of the test (Max = 32)	14·1	16·4	16·2	13·8	11·8	15·3
Mean decrement in performance between the first and second halves of the test	1·87	1·87	2·92	0·71	1·54	1·72

§ 4. Discussion

Among the four conditions there are three main comparisons to be discussed, those of the Paced Regular Condition with the Unpaced, with the Paced Irregular, and with the Continuous Display Conditions. The implications of the results of these comparisons will be considered in turn and, finally, the question of individual differences will be discussed.

Paced versus Unpaced Presentation

It has been known for some time (Mackworth 1950) that under certain conditions the efficiency of signal detection in watchkeeping may decline considerably with time spent on the task. Broadbent (1953) has suggested that this decline may be due to the increasing incidence of short periods when attention is turned away from the work; if the task is a paced one, as is the case with most watchkeeping, signals may occur during these periods and will be missed if they do not outlast them. In support of this argument he noted one or two rare instances of unpaced watchkeeping in which no decline in signal detection occurred. However, this could have been due not to the unpaced nature of the task but to some other feature of it, and this interpretation is supported by the present comparison of paced and unpaced watchkeeping in the *same* task when both forms of presentation showed a significant and roughly similar decline in efficiency. We have now to consider the reasons for this.

Let us first examine the case for expecting the decrement in signal detection to be less in unpaced watchkeeping than in paced. It can be argued that vigilance is a special case of serial choice reaction which differs from more conventional forms in possessing some of the following distinctive features: (*a*) there are few choices (often only two), (*b*) they are presented at a relatively

slow rate, (*c*) their frequency distribution is heavily biased towards one alternative, and (*d*) the displays which have to be distinguished are very similar.

If then it be agreed that we can generalize from the serial choice reaction task to that of vigilance it may be that Broadbent's (1953) finding that unpaced serial reactions yielded fewer errors, both of commission and omission, than paced might also hold good for vigilance tasks. Unfortunately for this suggestion, as we have seen, the expected reduction of errors or failures of signal detection did not occur. This is disappointing from a practical point of view but it may be useful theoretically to consider why. Two possible explanations are, firstly that a vigilance task is in some way fundamentally different from the conventional serial reaction, or secondly, that it is not always true to say that unpacing a serial reaction task will prevent an effect of fatigue appearing in errors. The latter explanation appears preferable for the following reasons.

The present author gave subjects twelve 30 min. tests over a period of six weeks (Wilkinson 1961) with a serial reaction task designed by Leonard (1959) and resembling in principle one used by Bills (1931). It was found that as subjects became highly practised not only did their response times become slower and more variable, as is usual, but that they also made more errors. It seems reasonable to assume that the high level of practice caused the subjects to work more 'automatically' so that when a 'block' or lapse of attention occurred they still responded—although inaccurately—instead of waiting until it had passed to make a slower but correct response. It may be that this is the explanation of the continued incidence of errors of omission in unpaced vigilance tasks: subjects may have been responding 'automatically' and still calling for displays during their lapses of attention, so that signals could still occur and be missed during these periods of poor concentration.

If this view is correct, it has still to be explained why this 'automaticity' of response was present in a vigilance task which was only performed twice compared with the twelve repetitions of the serial reaction task. The reason may be that those features which make the vigilance task a special case of serial reaction are just the ones which may encourage the early adoption of an 'automatic' form of responding. Both the small number of choices and the low rate of data presentation should make for quick learning and early 'automaticity', and an 'automatic' response to the buzz followed by no further signal would have been encouraged by the fact of its being so much more frequent than the buzz followed by a signal. The similarity of the 'signal' and the 'no signal' sequences would make it easy to give the 'automatic' response even when a signal did follow the buzz.

Thus the present result may at once be explained by, and provide support for, an hypothesis that unpacing of serial reaction tasks only avoids errors in the earlier stages of practice, as indeed Broadbent suggested as a corollary to his finding. The more the form of the task encourages quick learning the sooner will accuracy as well as speed be affected, and if vigilance tasks are to be regarded as approaching an extreme in this respect, there may be little or no effect on errors of changing from paced to unpaced presentation.

It may be, of course, that some examples of vigilance will not approach this extreme as closely as does the present one, and in these there may be more

advantage to be gained in using an unpaced presentation; the same might also apply where levels of motivation are higher—in the present experiment no particular attempt was made to motivate the subjects more strongly than would be the case in normal work. Clearly the present comparison of paced with unpaced presentation of vigilance data should be extended to other variants of the work before we think of generalizing from the present finding to all vigilance tasks.

Comparison of Paced Regular and Continuous Display Conditions

Oswald (1959) and Gastaut (1961) have suggested that a continuous and insistently repetitive feature in the environment may induce sleep, and the idea is supported by subjective reports of the soporific effect of monotonously repetitive sounds, such as droning machinery or the rhythmic chatter of train wheels. The Paced Regular condition may be thought to offer a similar environment in that it represents an important class of vigilance task in which a succession of discrete displays are presented for inspection at regular intervals of time. The Continuous Display condition, on the other hand, represents a form of vigilance task in which there are no events of importance other than the occasional signals; and for this reason it might be argued that this form of task should be less likely to induce a move towards sleep and a decline in signal detection. This, as we have seen, did not happen: similar decrements in performance occurred whether the repetitive $4\frac{1}{2}$ sec buzz was present or absent.

It might perhaps be suggested that the level of arousal is an unimportant factor in maintenance of vigilance, but the known effect of lack of sleep on watchkeeping (Wilkinson 1960) discounts this explanation. Instead the present results should, perhaps, discourage generalization from the laboratory conditions of Oswald and of Gastaut to other working situations, implying that the effect of a monotonously repetitive feature may vary greatly from one situation to another.

Comparison of the Paced Regular and Paced Irregular Conditions

It has been suggested (Wilkinson 1958) that as a test becomes less predictable it may maintain a higher level of arousal in the subject, particularly when he has lost sleep. If this is important in maintaining alertness in watchkeeping among normal as well as sleep-deprived subjects, the greater unpredictability of the irregular presentation should have contributed to the maintenance of vigilance in the present experiment. Its failure to do so argues against the importance of the predictability of the test as a factor in these situations.

4.1. *Individual Differences and Different Types of Ability*

Perhaps the most striking features of the results were, firstly, the very wide individual differences in ability to do this work, which were unrelated to measures of intelligence, neuroticism and extroversion, and secondly the indication that two types of ability were involved. Ability to detect signals, of which individual differences were reasonably consistent from test to test, was distinguished from the maintaining of a steady level of signal detection, at which individual differences were *not* consistent from test to test. Pre-

sumably, different factors are important in each. Ability to see signals may depend mainly on relatively stable factors such as visual acuity. The ability to go on seeing signals for a long period, on the other hand, may be subject to more labile factors which can be influenced by variables not always controlled by the experimenter, for example amount of practice, state of health, quality of sleep and time of day. Perhaps these variables must be considered and controlled more carefully than hitherto if real progress is to be made in understanding the nature of the vigilance decrement.

This work was carried out under the direction of D. E. Broadbent. Subjects and administrative help were provided by the Royal Navy and financial assistance by the Medical Research Council. All these contributions are gratefully acknowledged.

Dans un grand nombre de tâches de vigilance, on demande de détecter un évènement critique ou " signal " qui apparaît de manière fortuite dans une longue série de signaux neutres présentés au sujet de façon automatique et à des intervalles de temps réguliers. On peut se demander si la détection n'est pas plus aisée si les signaux neutres sont présentés :

(*a*) automatiquement, mais à des intervalles de temps irréguliers ;

(*b*) non automatiquement, mais déclenchés par le sujet ;

(*c*) de façon permanente, formant ainsi un fond de " bruit " sur lequel vient se plaquer le signal fortuit.

Ces trois types de présentation ont été comparés avec le type standard mentionné plus haut, mais aucun des trois ne s'avère supérieur à celui-ci. Le nombre total des signaux détectés est sensiblement le même dans les trois types de présentation et le niveau de détection baisse de façon significative tout au long de la période d'observation, quel que soit le type choisi.

La comparaison du type standard avec respectivement les types (*a*), (*b*) et (*c*) nous incite à penser :

(1) que la prévisibilité des signaux du test n'est pas importante pour caractériser la détérioration du niveau de vigilance,

(2) que lorsque le sujet déclenche lui-même les signaux, il peut se produire qu'il le fasse de façon automatique au cours d'une baisse de son niveau d'attention et qu'ainsi le nombre de signaux non perçus soit finalement le même que si les signaux avaient été présentés automatiquement par une machine. Peut-on affirmer que, de façon générale, la fatigue détériore essentiellement la rapidité au cours du travail à cadence libre et la précision au cours du travail à cadence automatique?

(3) que les mesures de l'intelligence, de la tendance néurotique et de l'extroversion ne sont pas en relation avec le score des signaux vus, ni avec le degré de détérioration de la performance. Cette constatation est de peu d'importance en ce qui concerne le degré de détérioration étant donné la très faible fidélité test-retest relative aux caractéristiques individuelles de détérioration de la vigilance. Bien qu'assez étonnant, ce fait est intéressant en lui-même.

Viele Ueberwachung-Aufgaben verlangen das Erkennen eines kritischen Merkmales oder " Signals ", das gelegentlich in einer langen Serie von Darbietungen erscheint, die automatisch in regelmässigen Zeitintervallen erfolgen. Es wurde die Frage untersucht, ob die Ueberwachung besser wird :

(*a*) wenn die Darbietungen automatisch aber in unregelmässigen Zeitintervallen erfolgen ;

(*b*) wenn die Darbietungen nicht automatisch, sondern auf Veranlassung des Beobachters erfolgen ;

(*c*) wenn die Darbietung nicht in getrennten Einheiten, sondern als kontinuierlicher " Hintergrund " geboten wird, vor dem gelegentlich ein kritisches Merkmal auftaucht.

Diese 3 Variationen wurden mit anfangs erwähnten Standardform verglichen, wobei stets der gleiche Ueberwachungstest zugrundegelegt wurde. Keine der Variationen ergab Vorteile gegenüber der Standardform : die Gesamtzahl der erkannten Signale war ungefähr gleich und die Zahl der entdeckten Signale nahm signifikant im Laufe der Ueberwachung ab, gleichviel welche Variation benutzt wurde.

Ein Vergleich der Variationen (*a*), (*b*) und (*c*) mit der Standardform führt zu folgender Anschauung : (1), dass die Möglichkeit, den Eintritt des Tests vorherzusagen, für das Nachlassen der Wachsamkeit unwichtig ist. (2), dass der Beobachter, der zu selbstgewählten Zeiten die

Darbietung veranlasst, das ebensoleicht während einer Wachsamkeits-Schwäche tun kann, und daher ebensogut Signale übersehen kann, wie bei automatischer Darbietung durch eine Maschine. Die Allgemeingültigkeit der Annahme wird in Frage gestellt, dass Ermüdung hauptsächlich zu Fehlern der Geschwindigkeit bei gebundener Arbeit, zu Fehlern der Genauigkeit dagegen bei freier Arbeit führt. (3), ein regelmässig wiederholtes Merkmal einer Darbietung braucht bei anhaltender Wachsamkeit nicht notwendig einzuschläfern oder voreingenommen zu machen.

Individuelle Messungen von Intelligenz, neurotischer Veranlagung oder Extrovertiert-Sein stehen in keiner Beziehung zu der Wachsamkeit und ihrem Nachlassen während des Tests. Für das Nachlassen bedeutet dieses Ergebnis wenig, da es in seinem Umfang von Versuch zu Versuch stark schwankt, ein an sich interessanter, wenn auch störender Befund.

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BOOK REVIEWS

Statistical Theory of Communication. By Y. W. Lee. (John Wiley & Sons Inc., 1960.) [Pp. xvii+509.] £6 14*s*. 0*d*.

It is now three decades since the theory of generalized harmonic analysis began to take shape in the mind of Norbert Wiener. At first he was concerned just with the study of Brownian Motion, and it was not until almost twelve years later that he perceived that this same theory, properly developed, was the key to the understanding of communication systems. To the ergonomist this would have had little significance but for the parallel development of feedback control theory and the closely allied field of simulation. It is now accepted, sometimes with much trepidation, and sometimes with excessive enthusiasm, that human behaviour can, in some situations, be regarded as a feedback control system; albeit, a highly complex, and as yet indefinable one. If the analogy is acceptable, then it immediately becomes possible to use the full power of Wiener's theory, since feedback control systems and communication systems are, in general, one and the same. Hence it is reasonable to state at the beginning of this review that this book is relevant and important.

Up to Wiener's time harmonic analysis of communication networks had been confined to systems excited by either periodic or aperiodic (transient) functions. However, it had been recognised that all systems in the real world exhibited random qualities. The central idea of Wiener was that both messages and noise were essentially random. Clearly if the messages were not random they could be predicted, this in turn means that a message is known before it arrives, and would therefore contain no information. Thus the knowledge of communication systems was incomplete until their behaviour to probabilistic stimuli could be analysed. Wiener succeeded in fusing the statistical theory of random functions with the theory of harmonic analysis ; a feat which has provided a major advance in many technologies.

This book, following a handful of earlier texts, sets out to provide the fundamentals of generalized harmonic analysis. It is a highly mathematical work and is intended primarily for electrical engineers well versed in network or control theory. However, because of the clarity of explanation, and the skilful way the reader is led through the network of inter-related theorems and postulates, no very heavy intellectual demands are required for each individual step in the argument.

The construction of the book is nineteen chapters of relentless progression, from straightforward harmonic analysis of periodic and aperiodic functions as one starting point, and probability theory as another, through to correlation theory applied to randomly excited linear systems. At chapter 9 the basic concepts and mathematical tools previously derived are concisely summarized. Then follows the theory of detection of periodic components and measurement techniques, and a chapter devoted to deriving the fundamental relations for linear systems. The most important aspect of this theory is its application to the synthesis of optimum filters. The remaining six chapters are concerned with the development of this subject, the last two, on the use of orthonormal functions, being part of the author's own special contribution to the art.

In stopping at this point the book perhaps falls short of its brief title, since no mention is given of systems with simple constraints, or of other non-linearities. The author has undoubtedly used all the advantages of a close collaboration with Wiener, and of many years in teaching this subject, to produce one of the best interpretations of Wiener's work yet available. Those wishing to understand and use correlation techniques for mechanisms or organisms stimulated by stationary random processes are strongly recommended to refer to this volume.

K. C. Garner.

La Sélection Professionnelle. By SUZANNE PACAUD. (Paris : Presses Universitaires de France, 1959.) [Pp. 178.] 7.00 N.F.

THIS is the eighth—and in general the best—of a series of monographs on various psychological topics, under the general editorship of M. Paul Fraisse.

Mme Pacaud has had long experience of research into methods of selection, and her book draws very much on her own findings in various fields. The first three chapters give a short discussion of background to the development of psychological testing (particularly in France) both in selection and in vocational guidance ; they include a very brief social history of present day concepts of selection and training. The main part of the book discusses a number of general problems underlying selection by tests. This is mostly familiar ground, but it is well argued and presented; and many of the studies quoted are likely to be new to English readers.

The central theme of the book is that in all cases the only really sound starting point for establishing selection criteria is a thorough—and essentially psychological—study of the job. Too often indeed do tests (e.g. of intelligence) get used for selection merely because of being reliable and valid tests, although their validity may in fact not be relevant to the particular job. When ' special ' tests are constructed these, too often also, are hastily thought up on the basis of little more than a brief look at the work with a few guesses about the nature of the task. The painstaking care advocated by Mme Pacaud is well worthy of reiteration.

J. HOPKINS.

General Systems, Yearbook of the Society for General Systems Research, Volume IV. By LUDWIG VON BERTALANFFY and ANATOL RAPOPORT. (Michigan : Society for General Systems Research, 1959.) [Pp. 247+xxiii.] $7.50.

THIS book contains fourteen contributions, exactly half of which are reprinted from other books or journals. They are grouped under three main headings.

Concepts of Biology. " Animal Behaviour as System Reaction : Orientation Toward Light and Gravity in the Resting Postures of Butterflies (Vanessa) ". An English translation of Paul Weiss's 1925 paper.

" Evolutionary Concepts in Behavioral Science : Organic Evolution and the Genetical Theory of Natural Selection ". By W. M. S. Russell.

" The Problem of Biological Regulation and its Evolution in Medical View ". (reprint) by Hans Kment.

Organization Theory. " Thoughts on Organization Theory and a Review of Two Conferences ", by Anatol Rapoport and W. J. Horvath.

" Concept of the Social Organization ", by E. Wight Bakke (reprint).

" Understanding Organizational Change ", by Chris Argyris.

" Efficient and Viable Organizational Forms ", by Jacob Marschak (reprint).

" Games, Decisions and Organizations ", by Russell L. Ackoff.

" Artificial Organisms ", by Gordon Pask.

" Digital Simulation of an Evolutionary Process ", by George J. Friedman.

" Explorations in the Realm of Organization Theory ", by Richard L. Meier (reprint).

Theories of Stress. " Psychological Stress : A Review of Definitions and Experimental Research ", by Fred E. Horvath.

" The Measurement of Human Adaptation to Stressful Environments ", by S. I. Cohen, A. J. Silverman and B. M. Shmavonian (reprint).

" The Concept of Stress in Relation to the Disorganization of Human Behavior ", by Geoffrey Vickers (reprint).

This is a curious compilation and it defies generalization. What function does it serve to reprint so many articles in a book like this ? Perhaps the editors intended it to be nothing more than a collection of supplementary readings. If this is the case, to whom is it addressed ? I find it difficult to believe that there are to-day generalists so catholic in their interests and so profound of intellect that they can and will read all these contributions. These are, after all, highly technical articles—they are not of the popular science variety. Perhaps, then, the aim of the volume is to

provide a denotative definition of the field of systems research. But if one looks at the content of this volume, and those of previous ones, it appears that " systems research " is synonymous with science. Frankly, this left me with the feeling that I had been hoodwinked.

Many of the individual articles are quite good, however. If you have had trouble finding one or another of these articles in your library, here is another place to look.

A. CHAPANIS.

The Human Element in Research Management. By B. E. NOLTINGK. (London : Elsevier Publishing Co., 1959.) [Pp. 91.] 9*s*. 6*d*.

THIS book is pleasantly and fluently written. It is like a collection of addresses or even sermons, each one headed by a text from somewhere in the Bible, mostly the wisdom books. These addresses or sermons, each one a chapter, are composed of thoughts, reflections, meditations and recommendations, many of which will have been thought of before by many people engaged in research management. The author protects himself against charges of plagiarism or petty larceny in his preface where he says that he has set down his own ideas in their entirety before consulting any previous writers. It is not clear for whom the book is written, whether it is for research managers or for those who hope to be research managers some day. I think that most people will know that successful management in anything, research or what you will, requires strong common sense, sound judgement, fair mindedness, good manners and politeness to all, even temper and self discipline. If anyone has got all these things by nature he is fortunate indeed and he will not need to read books about it.

H. BRADLEY.

Psychology and Human Performance. An Introduction to Psychology. By ROBERT M. GAGNE and EDWIN A. FLEISHMAN. (New York : Holt & Co., 1959.) [Pp. xiii, 493.] $7.25.

READERS of this Journal will not require the publisher's assurance that " Experimental psychologists have contributed enormously to our understanding of the kinds of behaviour men exhibit in performing work." But what should they expect when they are also told that " Here, for the first time, this knowledge is presented in such a form that the student without a background of psychological study can understand both the general principles of the science and what it has to tell us about man as a behaving organism " ?

The present reviewer has recommended the book to students with special interests in applied experimental psychology, but he is not convinced that any particular success has attended these efforts. Not a few readers refuse to venture beyond chapter 1, " The Science of Behaviour," where the usual small talk about ' scientific methodology ' is to be found, whilst others tend to give up at the level of chapter 4, " Motivation ". Only one or two brave it for long enough to reach chapter 8, " Motor Skills," which promises to deal, among others, with the important topic of transfer of training. Here however, they are apt to ask whether it is really fair and/or helpful to be told in the 1960's, by Professor Gagne of all people, that " High positive transfer depends on the similarity of stimuli and responses in the ' old ' and ' new ' tasks " (page 262)? There is obviously more to it than this essentially common-sense view suggests, and no useful purpose seems to be achieved by concealing the enormous complexity of the problem behind the smoke screen of a few heavily significant figures. Certainly the intelligent student is very likely to object and possibly to refuse to inspect the content of the remaining chapters, headed : 2. Basic components of behaviour ; 3. Functions of the behaviour system ; 5. Human abilities ; 6. Learning and retention ; 7. Discrimination and identification ; 9. Concepts and thinking ; 10. Social behaviour ; 11 and 12. Jobs and personnel selection ; 13. Training; and 14. Engineering psychology. Each chapter has a useful summary, as well as a short list of suggested reading, and there is a generous, perhaps over generous, number of diagrams, figures and tables to accompany the text. Only a

few printing errors interfere with the reading, but they are of little consequence (e.g. the date of the Foxboro Company's reports on tracking performance is given as 1934 on p. 455 ; a well known psychologist is referred to on p. 481 as E. Steller.) The subject index is adequate, but the author index is limited to American workers apart from Chocholle (auditory reaction times), Grindley (knowledge of results), Hick (choice reaction times), Provins (arm movements), Welford (skill and ageing), Wyatt (incentives), and Professor Jean Piaget. Surprisingly, no attempt is made to introduce the student to information theory.

The foregoing comments are not intended to imply that the book as a whole is inferior to other American introductory texts. Indeed it is a good one of its kind but like the others it fails to make clear to the student a number of all important points, e.g. that experimental psychological research aims at the understanding of certain processes (such as information detection, storage and retrieval ; inferential construction, symbolic formulation and execution of plans ; etc.) in terms of mediating structures, rather than at the level of ' manipulation of behaviour ' ; that psychologists have no monopoly of such interests (almost all that is worth knowing in this vast field comes from a combined effort of several disciplines) ; that in this difficult, but exciting, exercise superfluous quantification and ' hypothetico-deductive ' rigour are of little help ; that whilst striving for greater precision, it is desirable to preserve some measure of tolerance towards the remaining ignorances ; and that rather than to allow oneself the luxury of becoming self-consciously ' scientific,' it is prudent, on many issues, to remain agnostic.

J. Szafran.

Ergonomics : the Scientific Approach to Making Work Human. Reprinted from the " International Labour Review " Vol. LXXXIII, No. 1, January, 1961.

The aim of this article is to present some of the results of this research and to indicate how it has been and can be applied. After a general introduction, the paper describes the historical development of ergonomics, outlines the various fields of human sciences concerned, and discusses the practical application of ergonomics in industry from the economic and the humanitarian point of view. A list of selected references is appended.

ERGONOMICS RESEARCH SOCIETY
ANNUAL CONFERENCE 1961
ABSTRACTS OF PAPERS

BLOOD ALCOHOL LEVEL AND WORK ACCIDENTS

By B. Metz, F. Marcoux, and S. Ledermann
University of Strasbourg, France

After a pilot-study conducted in 1956–1957 on 650 control workers and 350 injured workers in a steel plant, a new study was undertaken in six plants with a total manpower of over 20,000 people, of whom 3,080 control workers and 1,009 injured workers were investigated for blood alcohol. Blood samples, obtained by stabbing the ear lobe or the finger tip, were examined for ethyl-alcohol content by the Widmark microanalysis procedure. For all subjects, control as well as injured, personal history data were recorded in order that various factors of alcoholization or of exposure to accidents might be investigated.

The data have been interpreted by comparing the distributions of the blood alcohol levels in the various groups of people classified according to the factors recorded.

The influence of the blood alcohol level on safety can be measured by two coefficients :

(*a*) *The alcoholaemic accident probability coefficient*, which is the ratio of the probability of accident in the high blood alcohol group (above 0·25 g/l.) to the probability of accident in the low blood alcohol group (under 0·25 g/l.). The weighted average of the coefficients found in the various plants reaches a value of 1·47 which means that the probability of accident is increased by about 50 per cent in the high blood alcohol group.

(*b*) *The accident repetition coefficient*, which is the ratio of the probability of having two accidents or more when belonging to the high alcohol group to the probability of having two accidents or more when belonging to the low alcohol group. The weighted average of the coefficients found in the various plants reaches a value of 2, which means that the chance of a repeat accident in the high blood alcohol group is twice that in the low alcohol group.

MANUAL LIFTING OF LOADS

By P. A. van Wely
N. V. Philips' Gloeilampenfabrieken, Eindhoven, Netherlands

This paper deals with an investigation carried out by the Philips Ergonomics Group in Eindhoven, Holland, August 1960, into manual lifting of loads. One of the results of this investigation is that it appears to be statistically

significant that the physiological efficiency not only depends on the weight of the loads but also on the number of lifts per time-unit. Another conclusion is that lifting of heavy loads (>20 kg) is physiologically more efficiently performed in a stooping position than in an erect posture, with light weight loads just the other way about.

The methods of research, the statistical as well as the instrumental design, will be discussed. It is hoped to be demonstrated that it has been possible to get interesting conclusions with rather simple methods, with a small number of experimental subjects, and in a short time but with very careful and thorough planning.

OPERATIONAL VALIDITY IN MILITARY FIELD TRIALS

By N. H. Hayes

Army Operational Research Group, West Byfleet

Of all types of military testing the troop trial probably attains the highest level of operational realism. This realism is possible because we can study actual users handling equipment under real or simulated active service conditions. High testing realism is essential if we are to accept the suitability of equipments for future operations. Simulation is inevitable when there is no real life battlefield available, or when it is necessary to select particular characteristics of equipment or environment for test.

The military field test, as any other, must be controlled to an experimental plan if results which are scientifically and statistically valid are to be achieved. It is equally important that the results should be of reliable practical significance and of direct military application.

Operational validity—or the reliability of trial results as indicators of actual performance—is the most important criterion of good military testing. It depends on realism in field work and on the relevance of the experimental plan and of the data collected to the questions that have to be answered.

TOWARD A GENERAL THEORY OF HUMAN PERFORMANCE

By Laurence E. Morehouse

University of California, Los Angeles, U.S.A.

During pure and applied studies of man at work, and especially during the past four years while attempting to elucidate the stimulus for strength training, elements which might be underlying factors in all human efforts have suggested themselves. Some of these are:

1. The way in which the performer interprets the task.
   (*a*) Recognition—identity, personal responsibility
   (*b*) Importance—well being, survival, altruism
   (*c*) Avoidance—acceptance, staleness
   (*d*) Selection of method.

2. Personal organismic response to work.
   (*a*) Integrity—genetic, traumatic.
   (*b*) Homeostasis—resistance to change
   (*c*) Anxiety—inhibition
   (*d*) Conditioning—pre-start, adaptation, erasure
   (*e*) Volition—consciousness.
3. Training—susceptible factors.
   (*a*) Deinhibition
   (*b*) Coordination
   (*c*) Specificity—individual rhythm, work characteristics.
4. Modification by Environment.
   (*a*) Group interaction
   (*b*) Sensory input—ecological fatigue
   (*c*) Physical-chemical.

Some of these factors are already well developed in the literature of the work sciences, and these will not be detailed here. An attempt will be made to establish working hypotheses for the factors which remain to be more fully identified and explored.

LIGHTING AND INDUSTRIAL STRESS

By H. C. Weston
Formerly of the Institute of Ophthalmology, London

The part played by lighting in the causation of stress in people at work is considered with reference to some instructive examples. Recent changes in actual and recommended lighting practice aimed at the prevention of stress are discussed briefly.

THE DESIGNER'S DEMANDS UPON THE ERGONOMIST

By W. H. Mayall
Council of Industrial Design, London

The paper considers that, in general, the design process involves four main activities :

1. Statement of the problem.
2. Analysis of the problem.
3. Experimental solutions to the problem (preliminary synthesis).
4. Final synthesis.

All factors involved in the design process must be considered at each stage. Initial omission of any factor, though subsequently introduced, may lower the excellence of the final design. Treated as a design factor ergonomics is involved in the following ways at each stage :

For 1., there must be an awareness that human factors matter and the circumstances of human use must be known.

For 2., there must be methods of analysing the man/machine relationship.

For 3., there must be a supply of data and methods of experimental checking or simulation.

For 4., the ergonomic factor has to be incorporated to give the most effective synthesis of all design factors.

A design example illustrates these points and a general indication is given of how they may be tackled in different sections of industry. The paper concludes with an appeal for ergonomic instruction to align itself with the design process and for ergonomists to prepare readily assimilated data for designers, particularly with reference to the preparation of handbooks in a non-scientific language.

SAFETY HARNESSES FOR CARS

By H. C. W. Stockbridge and J. P. Dennis

Clothing and Equipment Physiological Research Establishment, Farnborough

The paper consists of a review of work on safety harnesses for cars carried out in America, Sweden and the United Kingdom.

The probability of a crash is estimated at one every 30 years or so. In 1959 some 1582 people were killed and 115,451 injured whilst travelling in vehicles.

American workers have estimated that an adequate restraining device would halve the number of deaths from car accidents. This restraining harness prevents occupants from being flung about inside the car and from damaging their heads and faces.

In the U.S.A. about half the crashes are as a result of front end impacts which decelerates the car rapidly while the body continues to move. A deceleration from 40 m.p.h. to rest in 2·7 ft represents 20 g. Types and makes of belts are described as ‘ the parachute harness ’, ‘ the diagonal ’ or ‘ the lap belt ’, each of whose effectiveness depends on the anchor points to the car and to consumer acceptability in ease of donning and doffing.

Two particular dangers are the ‘ whiplash ’ and ‘ jack knife ’ effects. Excessive elasticity in the harness slams its wearer back into his seat, while if only a lap belt is worn the body may ‘ jack knife ’ onto the fascia panel. In conclusion the British Standard is described and the need for further research indicated.

VENTILATION AND THE THERMAL ENVIRONMENT

By H. R. Lambie

Colt Ventilation Ltd., Surbiton, Surrey

Factory buildings exist to protect men and their enterprises from the weather—to form enclosures in which climate can be regulated.

The nature of the building itself exerts a powerful influence on the factory worker's thermal environment. Modern roof insulation reduces the cost of heating and so promotes comfort in winter, but current trends in roof design give rise to increased over-heating in summer.

Solar exposure, lay-out of heat-producing plant, emissivity of warm surfaces, degree of physical exertion, discomfort or stress caused by other factors such as dirt or noise, all influence the assessment of a ventilation problem.

The absence of an absolute standard of comfort applicable to all industrial conditions places calculation in the rôle of an aid to sound judgment, and puts a premium on the experience of the assessor and on his ability to interpret his own response to the environment under review. As the response of the worker's mind and body to his changed environment is the final criterion of success or failure it is always helpful to evaluate his views on the conditions existing before changes are made.

Lantern slides illustrate points from specific examples.

STUDIES OF BRIGHTNESS DISCRIMINATION AS A BASIS FOR EYE-MOVEMENTS RESEARCH

By N. S. Kirk

Division of the Senior Psychologist, Admiralty

During recent years a number of techniques have been developed to determine where the eyes are looking in a variety of visual tasks.

To know the line of regard at a particular moment, or the percentage of time spent looking in a particular direction is valuable, but insufficient. Additional information must be collected, concomitantly or independently, on the operator's efficiency at the task itself.

More specifically, if it is known where a radar operator is looking when a target is presented, this tells us little unless we also have information on the brightness sensitivity of the eyes to targets presented at varying degrees of eccentricity from the centre of the field of view.

As a preliminary to the study and control of eye-movements in the radar situation this information was collected from an experiment in which the results from two groups of subjects were compared. In one group were experienced air-traffic radar operators—the others were not but were given extensive training.

This experiment and the results obtained from it suggested, furthermore, a method for measuring eye-movements which requires none of the instrument finesse of other techniques. This will also be described.

RESEARCH AT THE U.S. NAVY ELECTRONICS LABORATORY, SAN DIEGO, CALIFORNIA ON BIO-ELECTRIC INDICATORS

By E. H. Kemp

Human Factors Division, U.S.N.E.L

Beginning in 1956, a versatile bio-electric facility was developed with shielded rooms, multi-channel recording devices both mechanical and electronic, and sensitive filters and amplifiers for isolating various faint responses. Much of the equipment was designed and built locally and technique was gradually improved for reducing drift, integrating responses, eliminating response artifacts and preparing unique programmes of stimuli.

After developing two-dimensional eye movement records accurate to approximately a degree, Ford, White, Eason and Bartlett conducted experiments in which eye movements were recorded while the subjects responded to temporal patterns of brief stimuli or searched for targets in structured displays as well as in a free field. A most recent study by Bartlett, Eason and White was concerned with latency of ocular fixation upon the second of two successive stimuli. Typically, if one stimulus has commanded visual attention, no response can be made to fixate upon a second until the eye has swung into fixation upon the first, and following that first response, the second fixation movement cannot be initiated except after a delay required by the central mechanisms in organizing the response.

Since 1958, electromyographic techniques have been developed by Eason and White for recording and interpreting muscular responses from a number of muscles in the body. Systematic studies have shown how EMG level varies with voluntary effort, fatigue, and task difficulty. Individuals have different but dependable EMG patterns which reflect the difficulty of tasks in which the physical work output is insignificant. Studies of pursuit rotor learning show interesting changes of perceptual and motor task difficulty with changes of target size.

ERGONOMIC PROBLEMS IN MANAGEMENT CONSULTANCY

By C. V. Jackson

Urwick, Orr, and Partners, Ltd.

The word Ergonomics is now known to most managers. Most realize that in seeking to increase productivity and to reduce fatigue, the ergonomist can extend the range of work study techniques. But present ergonomic information—for instance on relaxation allowances in hot environments and in sedentary mental tasks—is too sketchy to be easily applicable, and examples from consultancy experience indicate that the norm given by ergonomists for maximum permissible energy output is much below current practice.

When confronted by the paucity of workable solutions to such commonplace industrial problems, management may throw out the baby with the bath water. They may reject ergonomics without realizing its other widespread applications to design, and to training, and its potential as a marriage of technologies which can bring to bear a range of knowledge vastly different in kind as well as in degree from work study.

Such a rejection of ergonomics might render British products less competitive in world markets on price and on design, and the members of the Ergonomics Society should strive to provide simple rules-of-thumb. Management consultants could form a valuable link between research workers and management.

HEAT STRESS IN A GLASS FACTORY

By J. W. Snellen

Netherlands Institute for Preventive Medicine, Leyden, Netherlands

In some situations it is possible to evaluate the heat stress (i.e. the heat gain by radiation and convection) both with the formulae proposed by Hatch and

Haines and with the determination of the heat production by metabolism, the heat loss by evaporation and the rise in body temperature.

In other cases the climatic situation is too complicated for this approach. We met such conditions in a glass factory. A practical solution could be given however as a result of the study of the relationship between the temperature of a globe-thermometer mounted in a fixed and well defined position and the sweat rate of the worker working under this globe.

PHYSIOLOGICAL ASPECTS OF SHIFTWORK

By F. H. Bonjer

Netherlands Institute for Preventive Medicine, Leyden, Netherlands

Productivity, frequency of errors, physiological responses to well standardized work and the performance at different physiological and psycho-physiological tests of a group of subjects were compared at morning, afternoon and night shifts. No consistent difference in output, working capacity or test scores between the shifts could be demonstrated by the applied methods of investigation.

There was an outspoken physiological adaptation to night work occurring after a few days. This adaptation is probably completely lost however after a free weekend or even after a single off-day. Although there is no proof, it is believed that the adaptation of the diurnal rhythm of physiological functions to night shifts is an advantage.

WORK IN COLD ENVIRONMENT

By L. H. Wesseling

Laboratory of Occupational Hygiene, University of Amsterdam, Netherlands

The paper contains the preliminary results of a part of a project that originally has been set up to evaluate the workload of workers in cold stores. This work is done under circumstances in which temperature of the environment changes over a wide range from -30 to $+25$ °c, with little air-movement.

The experiments described in this paper are a part of a more elaborate research programme principally consisting of two parts:

1. The evaluation of the actual load during practical working conditions in different environments.
2. An experimental research on non-acclimatized subjects, who are accustomed to rather heavy muscular work in different climatic conditions.

In the preliminary experimental set-up six subjects (workers) have been observed during exposure to three different climatic conditions with air temperatures of $+15$, 0 and -20 °c respectively. The following experiments were accomplished:

(*a*) ergonomic testing on a bicycle ergometer ; 4 periods are studied : 20 w (3 min) 60, w (3 min) and 110 w (5 min);

(*b*) alternative periods of static load of the arm-muscles, not exceeding 25 per cent of maximal force.

(*c*) Quick tapping with two fingers until exhaustion; speed, pulse-rate and blood-pressure are estimated.
(*d*) Some psychological tests (reaction time, calculation-test a.o.).
(*e*) Skin sensitivity test.
During these experiments done in at least two sittings of an hour, without special acclimatization at the end of the working day, the subjects were clothed in a moderately heavy standard clothing.

The second part of the observations is concerned with the estimation of the actual circulatory load during normal work. During cold work the subjects then were clothed in their normally used heavy protective clothing.

REACTIONS OF PULSE-RATE AND BLOOD-PRESSURE IN DYNAMIC AND STATIC WORK

By G. C. E. Burger and L. H. Wesseling
Laboratory of Occupational Hygiene, University of Amsterdam
and H. C. Burger
Philips' Health Centre, Eindhoven, Netherlands

The relation between workload and workcapacity of men in the situation of industrial and experimental workloads is evaluated by estimating the circulatory load of work.

As parameters of circulatory load (' cardiac ' or ' circulatory ' cost of work) the reactions on work of pulse-rate and blood-pressure (systolic and diastolic) are used during and directly after work.

The influence of short periods of submaximal dynamic and static work is evaluated.

A comparison is made between reactions on two different types of dynamic work, bicycling and cranking.

A load of 15, 65 and 115 w in bicycling is found to be approximately equivalent with 10, 20–25 and 45–55 w in cranking (with one hand), when measured by its circulatory effects as mentioned above.

Standardization of some tests is briefly discussed and the influence of double testing in dynamic work, training effects of tests, the prevalence of overshoot reactions and the relation between observations at the end of a work-period and the very beginning of the restperiod will be mentioned.

A not very marked but rather consistent difference in patterns of reaction of diastolic blood-pressure was observed, whereas the reaction of pulse rate and systolic bloodpressure showed the same patterns in both types of work. The assumption was raised that this difference might be explained by difference in static load.

Therefore further observations were made concerning the reactions in strictly static loads of muscles of arms and legs. The load was submaximal, as a rule not exceeding 20 per cent of maximal force. The effects of static effort of arms and legs were compared and showed a difference in intensity of reaction.

Static loads were applied during one longer period or during some alternating short periods of static effort and rest. Blood-pressure and pulse-rate were measured at intervals of one minute throughout the experiment with the

auscultatory method (Korotkow), using an apparatus that allowed quick repetitive measurement.

An attempt has been made to confirm the results of these measurements by onbloody registration of systolic and diastolic blood-pressure and pulse-rate. Preliminary results seem to confirm the above mentioned findings.

The significance of the preliminary results obtained is briefly discussed, especially in regard to the application in industrial conditions.

THE RESPIRATORY EFFECTS OF WHOLE BODY VIBRATION

By J. Ernsting

R.A.F. Institute of Aviation Medicine, Farnborough, Hants

The respiratory effects of whole body vibration have been studied in six subjects. Each subject sat on a platform which was moved up and down in an approximately sinusoidal manner. The effects of frequencies of vibration between 1·7 and 9·5 c.p.s. have been investigated at peak accelerations of up to 1 G. Certain combinations of amplitude and frequency produced a marked increase in pulmonary ventilation without a significant increase in metabolic oxygen consumption. These changes were associated with an increase in the rate of carbon dioxide output and a fall in the arterial carbon dioxide tension. The mechanisms underlying this hyperventilation have been investigated by recording the respiratory flow patterns and intraoesophageal and intragastric pressures. In addition the modifying effects of added external resistance to respiration upon the responses to whole body vibration have been determined.

THE INFLUENCE OF SHIFT WORK ON HEALTH

A. Th. Groot Wesseldijk

N. V. Philips' Gloeilampenfabrieken, Eindhoven, Netherlands

In factories where work is done in shifts, a considerable percentage of the employees has in the course of years to be transferred for medical reasons to the permanent day shift. The extent to which shift work causes the symptoms of disease to appear, or aggravates an existing pathological condition, is difficult to judge. There is evidence that the incidence of peptic ulcer and nervous disorders is higher among shift workers.

In order to investigate whether shift work causes perceptible changes in some physiological reactions an investigation was carried out in which 60 shift workers worked nights for four weeks at a stretch. They were subjected to a number of physiological tests over a total period of eight weeks, which included four weeks of day work and four weeks of night work. It has not been possible to demonstrate any statistically significant difference between the results scored during the day shift and at various times during the night shift.

When shifts are changed certain vegetative body functions are subject to extra strain. Rapid and complete adaptation of these functions to the changed 24-hour rhythm appears to take place in only a few individuals.

Those individuals who adapt successfully lose adaptation as soon as they take a day off. Therefore it is erroneous to base theories regarding the optimum period on nights on the adaptability of vegetative functions.

PHYSIOLOGICAL AND MECHANICAL STUDIES OF MATERIAL HANDLING

By Ulf Åberg

Swedish MTM Association and Institute of Work Physiology, Stockholm, Sweden

The carrying and lifting of loads still very frequently occurs even in highly mechanized industries. Some of the problems which arise in this respect are: how large a maximal load can be safely allowed for each lifting action and how often can this action be performed, i.e. what is the maximal instantaneous effort and the long-time average of the mechanically produced work ? A series of investigations has been carried out in an attempt to answer these questions. The experiments have been performed both as laboratory and field trials but the laboratory trials have also had a rather strong practical connection.

The results of the following three investigations are reported:

Carrying weights in a rucksack while walking on a treadmill.
Lifting beer cases.
Baling operations in a pulp factory.

Measurements have been made primarily of oxygen intake, pulse rate and mechanical work produced. Throughout the experiments a description of the movements has been made by means of suitable work study techniques. In some of the tests electromyograms have been taken.

The results support the earlier findings by Atzler, Cathcart, and others, concerning the maximal load in relation to body weight. In the case of carrying on the back, energy consumption can be separated in two parts: one part caused by the vertical acceleration forces, and one part caused by the balancing of the load. This also seems to be valid for other forms of work, e.g. work with a wheel barrow. The pulp factory experiment shows a marked dependence on the relation between momentary work load and the distribution of pauses, in agreement with the findings of Christensen. Some of these results point to a serious drawback for older workers who are in the doubly unpleasant situation of working near the upper limit of their ability and at the same time, because of insufficient strength, being compelled to use a method which is inferior from an energy-spending point of view.

THE ENERGY EXPENDITURE OF COAL MINING

By P. W. Humphreys

National Coal Board, M.R.C. Unit for Research on Climate and Working Efficiency, Oxford

The determination of the total energy expenditure of men carrying out industrial work is a slow and arduous task if the conventional physiological methods are used. A more rewarding method is by (i) assessing the energy

expenditure of the most common tasks; (ii) making an accurate analysis of the time spent at the different tasks throughout the working day; and then (iii) obtaining the total energy expenditure by computation from (i) and (ii).

The energy expended by a large number of subjects on 26 set tasks at specific rates of work has been measured by the Douglas bag method. A time analysis of the tasks involved in hand-filling coal has been made by continuous observation on colliers at five different collieries. By the combination of these sets of values the total energy expenditure of the whole day's work underground has been calculated. The time analysis can be repeated at further collieries, and so the overall energy expenditure of different patterns of work can be found.

VIGILANCE AND AROUSAL

By D. R. Davies

Department of Psychology, University of Bristol

It is suggested that under conditions of partial deprivation vigilance performance will be depressed. Some experiments are described which seem to support this hypothesis.

A group of 12 subjects was tested under two conditions. In Condition 1 they were tested under normal vigilance conditions, and in Condition 2 under conditions of decreased sensory input to the eye, i.e. they were placed in a darkened room wearing dark goggles.

Their task was to listen to an hour-long tape recording which consisted of a series of digits read out in random order at the rate of one a second, and to detect any three successive odd digits. There were altogether 24 such signals, six in each quarter-hour period. The subjects were divided into two equal groups and one group received Condition 1 first and the other Condition 2. Subsequently, 13 blind subjects were tested on the same task.

The results show that fewer signals were detected by the blind group than by the other two groups, and that the sensorily deprived group detected fewer signals than the group tested under normal conditions.

The implications of these findings for the organization of complex control operations are discussed.

THE LEARNING OF NON-RANDOM SIGNAL SERIES

By G. S. Tune

Department of Psychology, University of Bristol

The speed and accuracy with which responses are made in skilled activities are dependent, among other things, on the probability of the signal preceding the response, and also on the sequence of stimuli preceding it. It has been found that, at least on two choice situations, human operators are incapable of generating a random series.

This has important implications for the learning and maintenance of skills, and an experimental evaluation of the learning of sequential dependencies, by evaluating the issued raised, might help in the understanding of skilled performance both inside and outside the laboratory.

A preliminary investigation is reported in which the learning of three non-random series of signals was examined, and attempts were made to determine the extent to which the learning of one series interfered with the subsequent learning of another. Results show the importance of the structure of signal series on the learning of it, and that learning is affected by the interference caused by alternate learning of a different series of signals.

PROBLEMS OF STIMULUS-DECODING

By P. F. Powesland

Unit for Research on Human Performance in Industry, University of Bristol

Some of the limitations of communication theory as a source of models of human behaviour are briefly discussed. A current experiment dealing with the relation between psychological uncertainty and display entropy in a choice-reaction task is described.

The hypothesis is that response-latency is governed by subjective uncertainty on the part of the operator, rather than by the objective entropy of the stimulus ensemble.

In a five-choice reaction task, subjects are given practice with each of three different stimulus codes, consisting respectively of signal lamps, digits and colours. In each case the display has five equiprobable states, and consequently an entropy of $\mathrm{Log}_2\, 5$.

In test trials the subjects are required to operate with a mixed code consisting of five signals taken from all three of the original codes. With this test-code the display still has five equiprobable states (each response being uniquely indicated by a particular signal) and an entropy of $\mathrm{Log}_2\, 5$.

It is predicted that if subjects are not informed as to the constraints upon the mixed code they will treat it as yielding 15 possible states for the display (i.e. three possible signals for each response), and their response times will accordingly approach these for an ensemble with entropy $\mathrm{Log}_2 15$. If the subjects are told that the mixed code makes use of only five signals, it is predicted that their response times will approach those obtained with a homogeneous code of entropy $\mathrm{Log}_2\, 5$, but may show some increase resulting from ‘ residual uncertainty ’.

TRAINING AND PERSONALITY AS DETERMINANTS OF EXERCISE HYPERVENTILATION

By K. H. Kemp and R. J. Shephard

Chemical Defence Experimental Establishment, Porton Down

Ventilatory and cardiac responses to the riding of a bicycle ergometer have been investigated on young and initially untrained male subjects during a

variety of short intensive training regimes involving both maximal and submaximal work. Rides were repeated thrice daily on each of five successive days.

A training schedule of five minute periods of maximal work at each attendance produced a negligible improvement of performance over this five day period; with longer periods (15 or 30 min) of heavy but sub-maximal work there was a progressive reduction of both the ventilatory and the cardiac response to exercise.

The magnitude of the increase in respiratory minute volume at the first exercise could be related to personality as assessed by the Maudsley Personality Inventory, and in many cases there was significant over-ventilation. Excessive ventilatory work can itself limit performance, and for this reason personality and the psychological approach to successive work periods can be important determinants both of initial working capacity and also of the response to a training regime.

ERGONOMICS RESEARCH SOCIETY ANNUAL CONFERENCE 1962

This will be held at the Loughborough College of Technology from April 9th-12th inclusive

Suggestions for papers of symposia on special topics will be welcomed by the Honorary Meetings Secretary (Mr. D. Wallis, Division of the Senior Psychologist, Manpower Department, Admiralty, Queen Anne's Mansions, London, S.W.1).

Anyone wishing to read a paper should submit a title as soon as possible, and in any case not later than October 31st, 1961.

ERGONOMICS RESEARCH SOCIETY

ANNUAL GENERAL MEETING

The Annual General Meeting was held at the Manor Hall, Bristol, on 17th April, 1961, at 8 p.m.

Dr. Bedford took the chair. There were 50 members present. The minutes of the previous meeting, which had been circulated, were approved.

The Hon. General Secretary said that there was one new feature of this particular Annual General Meeting. For the first time, in addition to the Council's nominees for the election of ordinary members of the Council, two further nominations had been received. There would therefore be a contested election, and he suggested that it would be as well to start the meeting by collecting ballot sheets to give the scrutineers time to go through the returns while other business was discussed. This procedure was agreed, and there was then a discussion about contested elections, at the end of which Mr. Shackel proposed, and Mr. Anderson seconded, that the Council of the Society should consider the wording of the Rules to implement a contested election. In support of this motion, Mr. Shackel said that his proposal implied that the Council should as a general rule nominate more candidates than there were vacancies, so that there would always be an election. Others felt that such a procedure would make it even more unlikely that nominations would be received from ordinary members, and Dr. Cotes proposed an amendment, seconded by Dr. Griew, that the Council should encourage members of the Society to nominative alternate names for election. This amendment was carried by 8 votes to 3, and Mr. Shackel's motion was lost by 17 votes to 11.

The Hon. General Secretary (Dr. Edholm) presented his report, in which he pointed out that the Council had approved the formation of two sections of the Society, the Industrial Section and the Group for Fitness and Training. The Councils of these two Sections were as follows:

INDUSTRIAL SECTION

Mr. P. Cavanagh
Mr. L. V. Green
Dr. A. H. Jones
Mr. B. Shackel
Miss I. M. Slade (*Secretary*)

GROUP FOR FITNESS AND TRAINING

Dr. J. E. Cotes
Mrs. J. I. Grieve
Mr. J. A. Jeffery
Mr. H. Littlewood
Dr. M. L. Thomson (*Secretary*)

Membership of these sections was open to all those who were interested. All ordinary members of the Society could, of course, attend meetings of the Sections without any further subscription or notification, but those who were either unable or unwilling to join the Society but who were interested in either Section, could apply for membership in that Section and would be able to attend its meetings, and would also be able to get the Journal *Ergonomics* at a reduced rate. The Hon. General Secretary reminded members that other Sections of the Society could be organized at any time, and that members had a right to take the initiative in this matter.

The Council of the Society had continued to discuss the problems of consultancy. A new questionnaire was being drawn up under the direction of a committee consisting of Miss Slade, Dr. Crossman, Dr. Jones and Mr. Stansfield. This questionnaire should reach members in the near future, and it was hoped that the returns would then be available to the Department of Scientific and Industrial Research, which could use the information to answer industrial enquiries.

An innovation at the present Conference was the first Society's Lecture, which was brilliantly given by Dr. Bedford. The Society's Lecture will, it is hoped, be given annually, but this would depend on the state of the finances of the Society. It would not necessarily be given on the occasion of the Annual Symposium, but would probably be an independent event given in London.

The Society has continued to grow, and a ceiling of 250 members was about to be reached. There were the continual problems before the Society of qualifications for membership and of the most satisfactory size of the membership. These questions would be dealt with later in the meeting.

The Hon. General Treasurer (Mr. Murrell) then presented his report. This was the first year following the raising of the subscription and the results had been much more favourable than the

Hon. General Treasurer had hoped. There had been a trivial loss of membership, and there was a satisfactory balance, in spite of the smaller amount of the subscription which was available for running the Society. There were two unusual features both on the Income and Expenditure side which almost balanced each other. On the Income side there was the repayment of Income Tax and also repayment for a sum of £40 from the Conference account. On the other hand, there was a substantial sum of legal charges, being the fees for the Solicitors who had so thoroughly examined the Rules of the Society and had also drawn up the necessary documents for the appointments of Dr. Edholm and Mr. Murrell as Trustees of the Society. These fees were, in fact, only a fraction of the charge of the normal cost of such work, and the thanks of the Society are due to Messrs. Oppenheimer, Nathan and Vandyk for their generosity.

The Hon. General Treasurer also mentioned the Society's Lecture, pointing out that now that the invested income was free of Income Tax it could be used for payment of the Lecturer's fee.

Both the Secretary's and the Treasurer's reports were accepted.

The Hon. Meetings Secretary (Mr. Wallis) presented his report, detailing the meetings which were planned for the forthcoming year. Mr. Wallis mentioned the help he had received from Dr. Cotes and Miss Slade in the arrangement of meetings.

The Hon. Membership Secretary (Dr. Hellon) was unable to be present, and in his absence Mr. Murrell gave a brief report. The present membership was 232 Ordinary Members and 35 Affiliated Members. There were 18 candidates for membership, and if they were all elected it would bring the number to 250, the present ceiling. The Council did not propose to raise this number, and there would be no further vacancies except for resignations and names removed for non-payment of subscriptions.

Dr. Floyd reported on the Journal, *Ergonomics*, stating that Mr. Singleton had been appointed Review Editor.

Election of Officers. The Chairman declared the following duly elected as Officers:

Chairman of Council:	J. S. Weiner
Hon. General Secretary:	H. Maule
Hon. General Treasurer:	K. F. H. Murrell
Hon. Membership Secretary:	R. F. Hellon
Hon. Conference Secretary:	S. Griew
Hon. Meetings Secretary:	D. Wallis

The results of the election for ordinary members of Council were:

E. H. Christensen	J. C. Jones
J. E. Cotes	Miss A. D. K. Peters
E. R. F. W. Crossman	A. Rodger
A. H. Jones	W. T. Singleton

Membership of the Society. The Chairman said that the Council of the Society had had many discussions during the year about qualifications for membership. A circular had been sent to all members setting out the following recommendations and they had been asked to vote ' Yes ' or ' No ' to them:

1. That two classes of membership be created—Member and Fellow.
2. That membership of the Society should be open to all interested in ergonomics and its applications.
3. That all future elections to membership of the Society should be into the grade of Member.
4. That the election of Fellows should be by transfer from the Members in accordance with regulations to be prescribed.
5. That Rule 48 should be amended to ensure that changes in the Rules of the Society shall require a simple majority of Fellows and of Members voting separately.

The first recommendation was in some ways the most important one and there was a very close vote on this. The Council therefore felt that the members should be able to discuss these recommendations fully before any formal proposition was made to change the Rules. A lively discussion followed. Mr. Shackel voiced the opinion of many when he said that the Society had first to distinguish clearly between research activities and the activities which would characterize and influence practitioners. On the other hand, many agreed with Mr. Rosenbaum, who thought that the formation of the special sections, particularly the Industrial Section, should go far to meet the membership needs of those engaged in industry who were interested in ergonomics but were not qualified under the present Rules to join the Society.

Professor Rodger said that he felt no great enthusiasm for the proposals, but wondered whether the best advice was to say ' not yet '. As the discussion had continued for a considerable time most members were in sympathy with this advice, and it was generally agreed that this should be submitted to the new Council.

INSTRUCTIONS TO CONTRIBUTORS

1. Articles for publication should be sent to one of the Editors or to any Member of the Editorial Board.

2. Papers must be in English, French or German. Every paper must be accompanied by a brief summary, and contributors are asked if possible to supply summaries in all three languages.

3. Authors should submit a typescript, double-spaced on one side of the paper only. Footnotes should be avoided. Summaries, tables and legends for diagrams should be typed on separate sheets. Authors must ensure that the lay-out of mathematical and other formulae is clear. The typescript must represent the final form in which the author wishes the article to appear. The cost of any alteration in proof other than printers' errors may be charged to the author.

4. Diagrams should be drawn in black ink on white card or tracing paper. They should normally be sufficiently large to allow reduction in printing and the lines should therefore be bold. **All lettering should be up to draughtsmanship standard, suitably drawn in Indian ink to allow for reduction in size.** No charges are made for reproducing tables, diagrams or half-tone illustrations, but diagrams not suitable for reproduction without redrawing may be redrawn at the Author's expense.

5. References in the text should be indicated by author's name followed by the date. They should be listed alphabetically at the end of the paper in the style illustrated by the following examples:

BARTLETT, F. C., 1943, Fatigue following highly skilled work. *Proc. roy. Soc.* B, **131**, 247–254.

BEDFORD, T., 1948, *Basic Principles of Ventilation and Heating* (London: H. K. Lewis).

LE GROS CLARK, W. E., 1954, The anatomy of work. In *Symposium on Human Factors in Equipment Design* (Edited by W. F. Floyd and A. T. Welford) (London: H. K. Lewis). Pp. 5–15.

Abbreviations should be as in the *World List of Scientific Periodicals*.

6. **Consideration for publication will gladly be given to papers which have previously had a limited circulation as research reports.** Submission of a paper implies, however, that it has not been published and will not be published elsewhere without the permission of the General Editor and the Publishers. Copyright in material accepted for publication is retained by the Journal, and reproduction in whole or in part is forbidden except under the terms of the *Fair Copying Declaration* of the Royal Society or with the written permission of the Publishers.

7. Authors will receive 25 copies of their contributions without charge. Additional copies may be ordered at the time of returning proofs. Prices for additional copies may be obtained from the Publishers.

8. Authors of papers of ergonomic interest published in other journals and of unpublished reports which are available on request, are invited to submit brief summaries to the Reviews Editor for inclusion in this journal. Summaries must be accompanied by a copy of the full paper.

Books and other material for review should be sent to the Reviews Editor.

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